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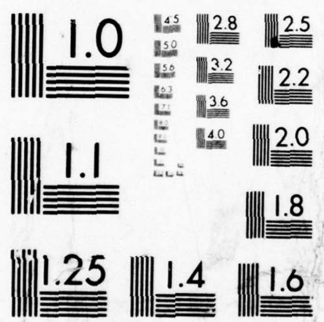
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16. Abstract

Workload is multidimensional and the reactions of individual pilots to increased task demands vary widely. While it has been found useful for various purposes in the aircraft design and development cycle to measure selected aspects of workload, to obtain an estimate of total pilot work and the potential for task overloading it has been necessary to rely primarily on broad measures supplied by pilots themselves. Thus, the final proof of crew capability continues to be obtained in actual test flight. An analysis of the total accident experience of U. S. certificated air-route carriers reveals that there is no evidence that a flight-deck crew of two in an appropriately designed aircraft is less safe than a crew of three pilots. A review of the procedures followed in the airworthiness certification of recent U. S. air-carrier aircraft indicates that manufacturers have demonstrated pilot workload in a fully modern and competent fashion, under the cognizance of FAA, and that actual crew complement approval has been based on both the results of the workload demonstrations and the experience gained in a significant flight test program.

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Workload; safety; aircraft accidents; aircraft certification; pilots; crew size.

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DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

1977-1978 TASK FORCE ON CREW WORKLOAD REPORT

DECEMBER 1978

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In the course of this compilation of documents and evidence and the review of these topics, the Task Force was given exceptional cooperation by all parties that were contacted. The names of individuals assisting the Task Force are too numerous to enumerate, but the Air Line Pilots Association, the Air Transport Association, the Aerospace Industries Association, and the three major manufacturers of turbojet airline aircraft, the Boeing Commercial Airplane Company, the Douglas Aircraft Company division of McDonnell-Douglas Corporation, and the Lockheed-California Company division of Lockheed Aircraft Corporation must be cited for outstanding cooperation. All provided both documents and extensive consultation. Team members originally designated were Charles D. House, selected from Flight Standards Service because of his close participation in certification tests on air carrier aircraft; Dr. Jack I. Laveson, representing NASA Applied Research and involved in pilot performance programs; and George C. Hay of FAA Engineering and Development. After completing a review of workload measurement technology, which was congruent with the contents of this report, Dr./Laveson returned to industry and was replaced by Dr. Richard L. Sulzer from the Human Engineering Branch, National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey. While NASA, because of budget constraints was unable to provide a replacement for Dr. Laveson, Mr. Gene E. Lyman, Director, Aeronautical Man-Vehicle Technical Division, has reviewed and approved our March 17, 1978, briefing to industry. Since only the members of the Task Force participated in all of the meetings and discussions held at a variety of locations, it should be kept in mind that the evaluations and conclusions of the Task Force represent the particular opinions of the Task Force members and are not necessarily shared by any of the contributors or approving authorities in the FAA. The Task Force has been in existence since May 31, 1977, a period of 18 months to the date of this summary report. The actual scope of data gathering and analysis, however, was less than this period of time suggests since all the members held other assignments to varying degrees. It is estimated that the total Task Force effort was equivalent to approximately one and one-half man-years of work.

Within the FAA, the Task Force wishes to express its appreciation for the total open-door policy established during our visits to both the DOT/FAA Western and Northwest Regions by their Regional Directors, Messrs. Stanton and Walk, respectively. Of particular note, valuable advice and counsel were received by the Task Force from Drs. Stanley R. Mohler, Robert E. Yanowitch, and Siegfried J. Gerathewohl of the FAA's Office of Aviation Medicine.

BACKGROUND

The purpose of this report is to summarize the information that was collected and studied by the Department of Transportation/Federal Aviation Administration (DOT/FAA) Task Force on Crew Workload. This Task Force was created to examine issues concerning crew complement determinations for turbojet aircraft. Conclusions reached by the Task Force were provided to the industry on March 17, 1978, and all of the reference information used by the Task Force was made available to interested parties at that time. In this report those elements considered most significant along with evaluations of the present state of relevant technology are appended to a more complete discussion of the specific issues.

In 1974, the Air Line Pilots Association (ALPA) requested that the FAA "...institute rulemaking on the crew complement problem...." According to the request, this would involve "...adversary hearings on the subject so that rulemaking may be undertaken with a complete factual record." (See reference 49). This request was dismissed as similar proposals to "open" the certification process to ALPA and others have been dismissed in the past (see reference 12). A certification procedure where parties other than the FAA have access to the manufacturers' data presents several complex problems, the most obvious of which concern manufacturers' proprietary data. Under existing regulations in the aircraft certification process, the FAA has access to all the manufacturers' design secrets, production processes, and performance data. If the sort of hearings ALPA has asked for were to be conducted, there appears to be no way to protect the proprietary data from disclosure to competitors, foreign manufacturers, and foreign governments, all of whom are seeking to supply transport category aircraft. Under the law, then, the airworthiness certification process, which is discussed in greater detail in a later section of this report, remains the sole responsibility of the FAA with the FAA exercising the power to hold public hearings only if necessary in particular instances as determined by the FAA (see reference 52).

The FAA does not design or dictate the design of an aircraft, an engine, wing, or other part of an aircraft, or the size of the crew. These design decisions are properly the province of the aircraft manufacturer, who normally makes design decisions in consultation with prospective customers and user groups. The specific role of the FAA is to collect and examine data and to test the aircraft to make a judgment, separate from the previous judgments made by the manufacturer, that the new aircraft does meet established standards of airworthiness. The regulation covering flight crew complement is FAR 25.1523, which became effective in 1965, and its Appendix D which enumerates the specific criteria used during crew complement determination.

Crew workload is the central element in determination of crew complement. The regulations do not limit the authority of aircraft operators to add pilots, navigators, observers, instructors, check pilots, or the like as deemed necessary. One place where the determinations made under the Federal Aviation Reguations, Part 25, have come under criticism is in the ruling that an aircraft that has been proposed for operation by two pilots could in fact be operated by that crew complement with optimum safety. Despite various statements to the contrary that have been advanced from time to time, the facts make it clear that turbojet airliners are being operated worldwide with either two or three member crews, according to the original design philosophy, cockpit configuration, and division of duties, and that there are no marked differences in safety records of the two versus three member aircraft. Since clarification of this question on safety, the revised central argument advanced by proponents of larger flight deck crews has been that current and projected future pilot workload may, in rare but predictable instances, exceed proper and safe levels. The proposed additional pilot is asserted to provide both a backup or redundant capability in cases of incapacitation or distraction from primary duties and an additional worker to permit redivision of responsibilities and consequent unburdening of the base crew. Since pilot incapacitation is demonstrably rare, and emergency operation by one pilot in aircraft certificated for a crew of two is routinely shown to be successful during certification, the main weight of the asserted safety increment falls to the sharing of duties with an alleged reduction in workload.

The tests conducted by FAA certification authorities on the current two member crew aircraft, the DC-9 and the B-737, showed that pilot workload is not excessive and, hence, does not require reduction. Labor-management negotiations may result in work sharing or extra-crew assignments, such as the agreement between ALPA and UAL to carry a third crew-member on the B-737. Such a practice is neither endorsed nor prohibited by any FAA rule, but there is a necessity for the airline to demonstrate crew capability when the extra crew-member is removed from his usual place, and the center seat of the B-737 is occupied by an FAA inspector. Hence, it is believed that the physical layout of a cockpit designed for two crew-members is not conducive to assignment of standard and important in-flight duties to an extra third crew member. Furthermore, it is suggested that presence of a crew-member for whom there was no designed position can produce distraction, irrelevant personal interaction, and interference with optimum crew performance. Since it cannot be proved conclusively that these are the inevitable results of adding a crew member for whom an active duty station was not provided in the basic aircraft

design, it is not possible to prove that safety is adversely affected by the presence of the extra crew-member. And the performance record over a large number of operations provides no final evidence that either the two member crew or the three member crew has the better safety record. Insofar as the raw accident rates have been compiled, the obtained differences do, however, favor the two member crew in the B-737.

FAR 25.1523 has been in force since 1965. Under this rule, the flight crew complement for a transport aircraft must be established so that it is sufficient for safe operation, considering: (a) the workload on individual crew-members; (b) the accessibility and ease of operation of necessary controls by the appropriate crew-member; and (c) the kind of operation authorized under FAR 25.1525. Basic workload functions and workload factors that must be considered are further specified in Appendix D to Part 25. These regulations were adopted after a thorough consultation with interested elements of the industry including flight-deck associations. The final form of the regulation with its appendix reflects the results of this consultation (see reference 19). Hence, it is clear that longstanding Federal regulations and the accepted usage of time with the airline industry identify pilot workload as highly significant in the determination of the flight crew complement. One factor that has been repeatedly brought to the attention of FAA by others is that the measurements, tests, and evaluations of workload must be made before the aircraft is produced in quantity and put in regular airline service. The final crew complement determination in the certification process is not made until the aircraft has been test flown under simulated airline operations. However, the preliminary decisions appropriate to workload are made earlier in the development cycle. These decisions are made at a stage when the completed aircraft is not available for test flight, and principal reliance must be placed on laboratory tests, synthetic computations, and subjective data. These bases for workload determinations have been criticized as varying in objectivity, adherence to dictates of scientific methodology, and relevance to the airline operating environment. To investigate these issues it was necessary for the Task Force to go beyond consideration of the airline operating safety records with two and three crew member aircraft and to delve into the technology of workload assessment as it exists here and abroad, in varied workplace settings and flight-deck situations, and in military and civilian settings. As will be seen in the body of this report, this technology is a diverse and complex field of specialization occupying the attention of many scientists and engineers in industry, government, and research institutions.

There is no single, universally accepted definition of pilot workload, and there is no single technique for estimating the probability of a pilot error under specified workloads. There are, however, many reasonable and specific definitions and methods of measurement and estimation that are in general and approved use for particular aspects of workload. Examples are found in both mathematical models and simulation testing of crew-member visibility, inside and outside the flight deck, crew-member ability to reach and manipulate controls, the time required to complete various procedures, and comparison testing of new and already proven crew-station designs. These and other methods are applied to the crew situation in new aircraft designs, and, generally speaking, an iterative procedure is followed with an increasing degree of realism in testing and increased precision of measurement as the development cycle progresses from concept to hardware. For these reasons the Task Force reviewed both the published literature on workload measurement and the actual procedures followed by aircraft companies and government authorities in conducting real-world design tests. The subject matter studied ranged from precise, abstract, research methods to non-quantitative opinion tabulation. The diversity of this material and the inability to discover a simple, total solution to the workload measurement problem made it desirable to attempt to sketch the broad outline of this complex technical area in this report. This Task Force studied the workload evaluation programs that were carried out more than a decade ago on the current two-man crew airliners, the DC-9 and the B-737, the subsequent effort on the series 30 and series 50 DC-9's, and from a methodological standpoint, later programs conducted by Boeing, Douglas, and Lockheed. Only completed certification programs were examined.

INTRODUCTION AND OVERVIEW

The Task Force on Crew Workload was organized on May 31, 1977, to review the crew complement aspects of aircraft certification (see, for example, reference 50).

This report completes the planned effort and consists of the following:

1. Introductory material, including the background issues discussed and the relation of workload to automation;

2. Discussion of the problems of measuring and defining pilot workload;

3. An outline of the methods presently in use to complete the design of transport cockpits;

4. A description of the FAA role in crew complement determination during the airworthiness certification process;

5. A summary of accident rates for two and three-crew aircraft.

The report also includes appendices in which details of past accident experience and illustrations of the crew-station design process are summarized.

The purpose of the Task Force on Crew Workload can be described in three areas:

1. To review the applicability and effectiveness of work that has been performed on crew complement determinations;

2. To review the relationships between crew complement and accident experience, and draw a conclusion as to whether crew complement is a factor in accidents, and

3. To determine whether additional work is needed on this subject, and to make recommendations to the Administrator.

FAA work in crew complement selection has been characterized in the following manner (see, for example, reference 2).

1. The best scientific and objective methods have not been used.

2. A workload ambiguity exists between short-haul two member crews and long-haul three member crews.

3. The systems engineering management process has not been applied to the human factors matter in the design of aircarrier aircraft. Therefore, the FAA should insure that this process is applied in future aircraft (see reference 2).

To begin its evaluation, the Task Force examined the historical precedents regarding the government's activities in aircraft design and certification. Under the Commerce Act of 1926, the Civil Aeronautics Act of 1938, and the Federal Aviation Act of 1958, as amended, the government has made no attempt to dictate aircraft design, but has established basic standards of safety. The FAA, and its predecessors, have implemented these basic standards of safety through regulation.

Specifically, regarding crew complement determinations, the Civil Aeronautics Board (CAB) in April 1948, established the 80,000 pound rule and 30,000 pound option as a basis for crew complement determinations. This came about after several very serious accidents involving the then new Douglas DC-6. The Federal Aviation Administration, on April 27, 1964, proposed the elimination of these weight rules, based on the experience of some 16 years of design evolution and improvement in airline safety, and substitution of flight crew member workload as the basic standard.

The consultative process by which the revised flight crew complement determination rules were adopted included extensive participation by flight deck associations (see reference 19). The International Brotherhood of Teamsters, representing flight engineers on certain airlines, opposed any change from the prior rules based on weight and stated that the proposal to establish section 25.1523 workload criteria for crew complement determination should be held in abeyance until the then Civil Aeronautics Board (CAB) issued the findings of a cockpit safety analysis then underway. This was done, the FAR amendment being issued only after completion of the study and consideration of its conclusions. The Flight Engineers International Association, representing additional third crew-members, submitted a detailed position including recognition of the importance of operating conditions as well as aircraft weight. The FAA concluded that Appendix D added to Part 25 includes all the factors that were cited as essential in certification. The completed CAB study (see reference 36) generally concurred with the proposed changes from weight rules to workload criteria. CAB (see reference 8) joined several other contributors in

stressing the importance of the pilot incapacitation possibility, which has been specifically included as one of the workload factors to be considered according to the appendix. The Air Transport Association sought to have the decision on crew size made final at the design stage, a proposal that was not accepted by the FAA. The FAA agrees that design studies must make assumptions about crew composition, but has required that the final determination of flight crew complement shall remain open until all the type certification flight tests are completed. ALPA stated that realistic operating problems could not be fully simulated in type certification proceedings and that demonstration flights were different from airline operations. This position has been reiterated by ALPA since that time (See reference 60), but the Task Force does not agree that cockpit design and crew composition cannot be properly evaluated in type certification. The Task Force believes that conditions representative of high workload and emergency situations can be included in the flight tests conducted prior to final airworthiness certification. Should operations be initiated in special or untested workload circumstances, the aircraft operator would have to demonstrate compliance with established requirements for safe operations under various other sections of the regulations. Following the broad participation of these and other interested parties, the flight crew complement requirements regulations were amended for aircraft certificated after January 1, 1964 (see references 17 and 18). These workload criteria have been in force since that time, and a considerable degree of experience has been obtained in their application to transport aircraft of varying designs.

Shortly thereafter, the McDonnell Douglas DC-9 was certificated and introduced into service, without controversy, as a two member crew aircraft under the certification base established by these rule changes. (The Douglas DC-9 was certificated on November 23, 1965. The first airplane, serial number 45695, was delivered to the user on September 30, 1966. That specific aircraft is still flying today with Texas International Airlines as N1301T.)

The Boeing 737 aircraft was certificated for two member operations. Subsequently, it was introduced into both domestic and overseas service. Under a Letter of Agreement, signed March 21, 1968 between United Air Lines (UAL) and the Airline Pilots in service with UAL as represented by ALPA International, the aircraft was test operated by both two and three member crews. Data were collected on pilot activities during those flights in an effort to settle the question of whether UAL should assign a third crew-member to all of its B-737 flights. After a one-year test period, ALPA still requested three member crew operations while UAL proposed a crew complement of two. This difference resulted in negotiation and an arbitration award,

dated March 31, 1970, that fixed the crew complement at three for UAL for the period of the next ensuing contract. This complement has been contained in subsequent contracts by UAL and Western Air Lines (WAL), which has followed the UAL precedent, although labor-management procedures have resulted in fixing the B-737 crew complement at two for the several other airlines using that aircraft. In the case of an airline operating in the Hawaiian Islands, arbitration resulted in a ruling for two member crew operation (see reference 4). Another case in the Alaska area resulted in a rejection by the airline of a three member crew proposal, a pilot strike, and subsequent two member crew operation by replacement pilots (see reference 5). The UAL matter was the first crew-complement dispute involving two member crews on new turbojet transports and has led to a continuing controversy.

The evaluation study organized by UAL and ALPA was accomplished during the one-year period between March 1968 and March 1969. The initial Letter of Agreement between the two parties stated, "The Evaluation Committee is charged with developing procedures which will insure a thorough and objective evaluation of the B-737 Flight Operations, comparing the two (2) and three (3) member crew operational concepts to determine: what shall be the crew complement on the B-737 airplane."

As stated in the subsequent report, the Committee observed that the initial goal "was overly ambitious" and "in this situation, no clear cut two-man or three-man decision can be expected from a study such as this" (see references 63 and 66). The Special Review Board Reports of February 10 and 22, 1969, set the rationale for United's introduction of B-737 three member crew operations. In light of the absence of the operational experience that exists today, coupled with an incomplete understanding, by the parties, of the certification process that existed when the B-737 was certificated, it can be understood how such a decision could have been made (See reference 3). Why was there an apparent misunderstanding, or incomplete understanding of the certification process, particularly the quantity and quality of testing that had been accomplished prior to the introduction of the B-737 into service? The Task Force does not have the answer to that question. Certainly this is not meant to be a criticism of the UAL or ALPA participants. A very considered and dedicated effort was expended by both parties. Although the study did not produce data supporting a clear-cut decision between the alternatives, a body of facts derived from regular line operations was produced and stands today as a valuable reference source.

A brief summary of FAA actions prior to introduction of the new DC-9 and B-737 aircraft into line service shows that a substantial amount of proof flying was, in fact, conducted. After

the actual period of functional and reliability flight testing by FAA and industry pilots, the pilot type-rating examination, given to a large number of airline pilots, verified the results of certification workload evaluations. In these flights the individual pilot had to make a showing of his competence to handle both normal and emergency situations. There was, of course, no third crew-member on those demonstrations. For type-rating, a process repeated for each prospective captain, these demonstrations of ability to resolve representative in-flight problems were made first in the training simulator and subsequently in actual flight. Route checks followed for the pilots with new type-ratings, constituting another series of demonstrations, now in the actual UAL route structure, that two crew member operation was safe. Finally, although under the UAL labor-management agreement on the B-737 a third crew-member was carried on the flight deck, FAA enroute flight checks are conducted with this third crew-member relegated to an observer's seat. The center seat, normally used by a third crew-member when such was carried, is reserved for the FAA inspector on an enroute check. Hence, the third crew-member cannot be assigned any duties that would require his not relocating his position. Since an enroute check by an FAA inspector could occur at any unexpected time, crew occupancy of the third seat could not be made essential to coordinated crew procedures. The experience gained during these enroute inspections verified the fact, previously demonstrated in certification, redemonstrated in type-rating checks, and re-redemonstrated in enroute checks, that two-pilot operation was safe. Hence, a substantial body of proof flying was done before the first two-pilot operation with passengers, and such proof flying has continued through enroute checks over the years.

Based upon what we have seen, the Task Force, while it would have disagreed technically with the determinations of the Special Review Board and subsequent Arbitration Panels that have recommended three member crew operations for B-737 on UAL, can understand how the lack of a thorough understanding of the certification process at the time of the critical arbitration hearings in 1968-69 could have led reasonable individuals to such a decision. In fact, the original finding emphasized that in the absence of the definitive proofs that could only be obtained over longer experience, it was better to tilt toward the three member crew for the immediate contract period, in effect saying "better safe than sorry."

Today, a vast amount of operational experience with two crew member turbojet aircraft is available. As may be seen from material in subsequent sections of this report, that experience shows that when considering three comparable aircraft, i.e., BAC-1-11, DC-9 and B-737, two versus three crew members, two

member operations have approximately 5 times the departure exposure cycles recorded for three member crew operations without a significant difference in accident rate. Generally, the raw accident rates are better for two than for three member crew operation, and hence, provide no evidence whatsoever that two crew member crew operation is less safe. The Task Force did not include the SUD AVIA SE 210 U. S. experience in the above computation since it is no longer in U.S. Service. However, it was operated by UAL as a three member crew aircraft and is included in the Appendix. It's accident rates, while lower than the DC-8, are well above those of the BAC-1-11, DC-9, and B-737 when these aircraft are operated by two member crews.

Comparisons within a single type are possible for one aircraft since UAL and WAL have used the larger crew, and other domestic airlines have used two member crews in the B-737. Comparing B-737 two versus three member crew operations, we found that three member crew operations have approximately four times the departures (exposure cycles) recorded for two member crew operations, but, the accident rate for three member crew operation is greater. Also, the only U.S. fatal accident involving a B-737 aircraft occurred with a three member crew operation. Since the actual numbers of accidents are small, and assumptions about homogeneity among the several airline samples cannot be verified, statistical analysis does not reveal a significant difference in the level of safety. The Task Force believes that the above important points should be emphasized. Thus, there does not appear to be a real difference in the level of safety between two and three member crews in aircraft designed appropriately for two member crew operations, i.e., BAC-1-11, DC-9, and B-737. Taking both the comparison between the three aircraft types operated by two versus the three member crew portion of B-737 operations and also the comparison within the single B-737 type, it is our opinion that these facts cannot support any claims of improved levels of safety in three member crew operations.

WORKLOAD AND AUTOMATION

Since 1964, crew complement has been decided on the basis of workloads imposed by particular flight deck designs and aspects of predicted operating environments, in accordance with FAR 25.1523 and Appendix D. The result of using this method of decision has been that some modern aircarrier aircraft have been approved for operation by two pilots while other aircraft have been certificated for two pilots plus a flight engineer. Aircraft manufacturers have been very much aware that approval for two-pilot operation requires design provisions that handle the important work done by the flight engineer in a cockpit designed for three member crew operation, and automation and simplification of a variety of systems such as cabin pressurization and fuel transfer have been adopted as the solution to this need. In a sense, then, automation has been increased to reduce system monitoring and adjustment work when there was an incentive to reduce crew workload.

The FAR's specifically require that all essential displays and controls be accessible to each of the pilots flying the aircraft (see reference 21). All aircraft, then, can be flown by one pilot, although this situation is never a planned occurrence in regular transport service. While all the "essential" instruments and controls are within the span of one pilot, this does not mean that everything that can become important in particular circumstances can be handled optimally by one pilot. For example, electrical, hydraulic, or fuel system problems, or any number of other low probability events may make it necessary to refer to the aircraft flight manual or to adjust circuit breakers, switches, and systems controls that are not conveniently located to the pilot's seat. Progress in control engineering has made it possible to automate most monitoring and system adjustment functions (see reference 65). Cabin pressurization systems, for example, can be manual (with a crew-member setting a control to maintain a desired differential between interior and exterior pressures or to hold cabin altitude to some uniform setting) they may be semi-automatic (with a crew-member energizing the system upon reaching some climb altitude and then monitoring the system with a manual override capability and a landing shutdown control), or they may be fully automated with nothing for the crew to do except for an initial setting prior to take-off (unless a pressurization failure is annunciated and then one simply effects an emergency aircraft descent). For many monitoring and control functions, full automation is more reliable and precise than either manual or semi-automatic modes. The machine can sense smaller excursions and match control actions more exactly to the demands than can a crew-member. Modern aircraft exhibit increasing use of automation and redundancy for systems such as pressurization, as well as for the traditional machine control functions, e.g., voltage regulation, where manual

control would be unthinkably inefficient. But increasing automation has costs, both for the creation of the system itself and for test and backup in case of possible failure.

The history of automation has been a progression toward increasing reliability and lower machine costs. Small and relatively inexpensive micro-processors now outperform what were considered giant computers twenty years ago, about the time the first turbojet transports were introduced (see reference 34). True "non-stop" type systems based on distributive processing, in which individual high-capacity units are capable of taking over functions from any failed components without loss of data, are being produced today. Hence, it is increasingly likely that flight decks can be designed to continue the present trend toward requiring fewer observations and fewer actions by human crew-members (see reference 24). At first, this might suggest that the trend in crew complement decisions would be in the direction of two members. In fact, this has not been the case. In gross outline, flight decks have evolved more slowly than might have been expected based on control engineering and automation progress. Part of the reason may be the fact that a decision to design for a three-man crew was made in the case of the wide-body generation of aircraft, and flight deck design followed from that decision. Since a third crew-member was assumed to be present from the earliest design stages, additional automation was not pushed; instead, the perceptual and response capabilities of the second officers were utilized to monitor and adjust various aircraft systems, and they were given a role in problem solving and fault correction utilizing the flight manual and associated checklists.

While automation of the systems monitoring functions usually displayed on the engineer's console was lagging, major changes were made in autopilots, integrated flight instruments, and avionics systems operated by the captain and first officer. Wide-body cockpits, then, present little or no simplification and few switch and display board changes from the narrow-body cockpits in the flight engineer's area. The improved avionics and automatic flight control systems used by the captain and first officer have, however, necessitated novel data input devices such as keyboards. These systems are not the sort of devices on which the crew performs trouble shooting and in-flight maintenance. Rather, they operate reliably unless some extreme condition, e.g., a lightning strike, renders them inoperative. If this happens the crew reverts to hand flying and raw-data displays. In any case the potential role of a third crew-member as a mechanic, engineer, or manual back-up for digital systems is severely limited. One of the principal duties performed by second officers in routine operations is the calculation of "numbers," writing these speed and power setting benchmarks on a slip of paper, and passing them forward

to the pilots, particularly for takeoff and approach guidance but also enroute. Typically, the information is obtained from tabulated data. The forthcoming "Flight Management Computer System," necessitated by the urgency of fuel efficient operation, even includes the forthcoming automation of the numbers calculation functions. Other routine duties are illustrated by the Load and Center-of-Gravity reports, made on company radio frequency prior to take-off; and the passenger complement, maintenance, and ETA data that may be needed by company dispatchers. Generally, there is no time urgency in such reports, and they can easily be deferred to low workload phases during enroute flight. Second officer functions of this sort illustrate, then, a kind of make-work that gives the third crew-member something to do.

These considerations indicate that while workload is the standard for crew-complement decisions between two and three persons, there is potentially a degree of flexibility available to the aircraft designer: workload at the engineer's station can be made higher if three crew-members are to be specified, or workload can be held to a lower level and automation can be substituted for human monitoring, control, and reporting functions, and status annunciators can be placed on the pilots' panels. Crew-station specialists at the principal transport aircraft manufacturing concerns told the Crew Workload Task Force that they believed they could design and demonstrate the reasonableness of either a two-crew or three-crew flight deck, as desired for a future aircraft. From this point-of-view, crew complement is largely a design specification arrived at by the potential customer airline and the manufacturer. They must adapt existing designs, with consideration of inputs from interested groups, such as the pilot associations.

Our research has shown that each successive model of the DC-9, to date, has incorporated human engineering improvements such that the cockpit panels were made simpler and the number of required pilot actions was reduced. Computer and simulator analyses showed a measurable reduction in both number of actions and the time required to complete them from the series 10 to the series 30, and again to the series 50. When ALPA representatives and other pilot groups examined the original DC-9 cockpit, they accepted the design as a satisfactory two-man crew flight deck. Similarly, no critical objection was taken to the DC-9 series 30. In the case of the "stretched" series 50, ALPA declared the aircraft unsatisfactory for two-man crew operation, although the ultimate result of the type certification procedures on crew complement set the crew at two, as it had for earlier DC-9's. All these DC-9 aircraft have been operated by two-man airline crews in numerous U. S. and foreign certificated air route carriers, and no instance is known of a larger standard crew in this civil transport.

Altogether, there were at least four formal meetings between the ALPA DC-9 Evaluation Committee and Douglas Aircraft prior to certification of the DC-9-10. Including meetings with ALPA Master Executive Councils (MEC) representing the pilots of individual airlines, there were at least five formal meetings on the DC-9 series 50, covering as many as six airline MEC's in a single meeting. While ALPA had adopted Article 20 in its association constitution calling for the series 50 to be a three-man crew aircraft, the airline pilot groups voting in the ALPA Convention actually voted to accept the DC-9-50 as a satisfactory two-man aircraft.

The prospect of labor-management strife over the crew-complement issue, with the potential for arbitration findings to take the conservative stance illustrated by the 1969 ALPA-UAL decision, despite the absence of hard factual evidence for the need to add extra crew, has inhibited progress in applying automation. Manufacturers told the Task Force that they desired to avoid precipitating conflict with pilot associations, despite their best technical judgments that better flight-deck designs would call for fewer and fewer flight engineer duties. This seems particularly unfortunate to engineers since past progress has shown conclusively that the true road to reliability is an optimum match-up of human perceptual and decision capabilities with increasingly automatic systems that reduce the need for routine crew adjustments. Adding extra crew members is a poor substitute for best design. When a proposed aircraft is presented in design form to the FAA for the initiation of certification proceedings, the manufacturer has already proposed the crew size. It is for the manfacturer to prove to the FAA that the requirements in Appendix D can be met with that crew size.

The philosophy underlying the design of current aircraft and the reliability demonstrations required in the type certification proceedings is that redundancy and provisions for back-up systems must insure that the aircraft is "fail safe." This means that critical, safety related functions and systems must be identified during the design and "iron-bird" test phases. Then, provisions must be made to handle critical failures in single and multiple occurrences. During the functional and reliability phase of the test, failures of electrical, avionic, hydraulic, display-control systems, etc., are deliberately inserted, and it must be shown that the failure does not result in loss of control. Automation, then, is approved only when it is shown to improve crew performance, while still providing for independent data sources and back-up procedures. The practical capabilities of these "failure" provisions are repeatedly demonstrated and, if necessary, improved to achieve the "fail-safe" criterion.

Summarizing, the information reviewed by the Crew Workload Task Force indicates that workload on the flight deck is the only reasonable criterion for determination of crew complement. In the past, it is possible that a rule relating a gross aircraft dimension such as weight, number of engines, or capacity to crew size may have been valid. But today, due to developments in automation, this is not the case. Either a large or a small aircraft can be designed for either a two or a three-man crew, depending on the application of modern control engineering. If it is decided to operate with a crew of two, an appropriate design of the flight deck can be produced, or, if it is desired to operate with a crew complement of three, various formerly manual operations can be retained, and control adjustments can be required to provide a flow of activity that will keep a third crew-member alert and usefully occupied. Against this background, and with recognition of the potential for future controversy about the adequacy of workload determinations, the present status of workload measurement technology shall be summarized.

DISCUSSION OF WORKLOAD DEFINITION AND MEASUREMENT

Before anything can be measured, it must be defined. Right at this basic point the problem of pilot workload becomes complex. There are, in fact, many definitions used by scientists and engineers specializing in workload evaluations, each reflecting the particular aspect of human performance that is most central to the work in question (see references 22, 23, 33, 53, 58, 73). Those most interested in physical reliability, work-rest cycles, and the effects of job stress naturally define workload in psychological/physiological terms and measure bodily responses such as rates of breathing and heartbeat, production of stress products, and the like (see reference 40). Those focusing on decision errors tend to define workload in terms of perceptual and cognitive task loadings and quantify data such as how many indicators must be examined and how much information processed. Others studying the puzzling phenomena of intentional or unintentional violation of safety rules, such as the failure to make altitude callouts in low visibility approaches, may define workload to include boredom, inattentiveness, lack of discipline, etc., that can be results of complacency, over-reliance on automatic devices, and personality conflicts.

It is clear that human error is not a linear function of either task demands or effort expended. Error may and does occur in diverse situations, not simply in instances of overwhelming stress. Furthermore, one of the conditions that may lead to human error is operator under-load (see reference 71). If human judgment and intervention are required only rarely, a phenomenon of over-reliance on automatic devices and complacency in the face of malfunctions may result. A degree of challenge and an experience of participation in the control loop, that is, a moderate degree of task demands, may lead to optimum performance (see references 54 and 67). Should additional task demands accrue, the pilot often shows skill in "load shedding," the practice of dropping out unessential portions of the control task to allow concentration on safety essentials. It is very unlikely, following this reasoning, that a situation could be generated in which the pilot was so overwhelmed by task demands that he would become unable to maintain altitude awareness. Since there are only a small number of recent turbojet accidents, there are not very many accident analyses available for study. Nonetheless, there can be found instances of moderate to low workloads when altitude awareness was lost (see reference 47).

While a simple relation between safety and workload such that more workload equates with less safety cannot be supported entirely, it is still reasonable to use workload as defined by Appendix D as a crew-size factor. This is because Appendix D lists the basic workload functions (essential areas of pilot activity), that are considered, enumerates the factors that are significant in

analyzing and demonstrating workload for crew complement determination, and notes that the crew determination is made with reference to particular operating rules. As discussed earlier, the final proof required for certification includes actual flight of the aircraft in functional and reliability testing. Appendix D enumerates the pilot activity that is to be observed during these proving flights and provides a specific list of factors on the basis of which workload is to be demonstrated.

These factors include increased workload associated with emergencies and crew-member incapacitation. Since Appendix D was published in 1964, the proponents of three member crews have not concentrated on criticism of the criteria themselves. Instead, they have most often taken one of two general lines. According to the first, for example, ALPA has asserted that "the manufacturers and the carriers would have us believe that the sole test of work accomplished by the cockpit crew is in the measurement of hand or eye motions" (see reference 68). This is obviously untrue with regard to certification since Appendix D specifies the criteria and these include a great deal more than eye and hand motions, for example "the degree and duration of concentrated mental and physical effort involved in normal operation and in diagnosing and coping with malfunctions and emergencies," and another six paragraphs of required tests and observations of overall crew capability to operate safely in the face of worst-case conditions. The second general argument advanced in criticism of approval of two-man crews is that the FAA use of Appendix D covers only a brief series of flight tests. It is sometimes said that actual airline operating conditions are more stringent, including difficulties with flight instruments that become inaccurate or hard to read, deficiencies of anti-ice or de-ice systems, unfavorable runway conditions, structural failures of older aircraft, and unpredicted weather, Air Traffic Control (ATC), and other demands on crew efficiency (see references 44 & 60). This claim by ALPA that functional and reliability flight tests are not stringent enough to represent actual airline operating difficulties is also untrue. For example, FAA and company pilots are included in the test crews, and these pilots have less time in type and less familiarity with the test routes than would be the case with subsequent airline operating crews. In addition, extremely rare and critical problems and failures, such as sudden and total incapacitation of the pilot flying the aircraft, and problems with critical safety systems are loaded into the test flights to a degree beyond anything expected in actual line operations. The test pilots have to cope with weather, ATC, system, and crew problems that come one after another and in conjunction to the point that workload is deliberately increased beyond expectations of actual line operations. The Task Force believes that the most important difference between these certification flights and subsequent line operations is that the

FAA tests are more demanding, not less, and that the pilots are looking for flaws in the design and have an immediate voice in the determination that crew arrangements are or are not safe and acceptable.

The importance of matching crew complement to the design philosophy and specific human engineering arrangements of any given cockpit were stressed by Hillman and Wilson who wrote that "... a flight deck designed for three-crew member operation cannot be optimal for two and ... a two member flight deck crew will be unbalanced and inefficient if operated by three." (See reference 32.) Supporting this point, several NTSB reports illustrate situations in which sudden third-man intervention would appear to be most difficult (see reference 46).

Manufacturers' tests in mock-ups, simulators, and laboratories of observable pilot activities, such as eye and hand motions, are conducted for the purpose of selecting among candidate designs and to improve and simplify work stations (see reference 54). Data produced by these "objective" test methods is never substituted for actual in-flight workload evaluation by the FAA. In addition, the functional and reliability flight tests are conducted with deliberate injection of rare and demanding emergency procedures, and the pilot sample includes persons with less experience on the routes than will be the case with subsequent airline service. Hence, while the number of hours flown is small compared to the total flying that will later be done by the type, a concentration is included of the most difficult circumstances, including weather, pilot incapacitation, relatively unfamiliar routes, and aircraft systems problems.

Furthermore, recent criticisms of FAA procedures used in determination of flight crew complement have emphasized the availability of scientific and objective methods of workload measurement. Thus, the argument has become inverted. Now, laboratory tests using methods developed in cockpit design efforts are advocated rather than reliance on in-flight testing (see reference 2).

The correct view of Appendix D is that it constitutes a detailed operational definition of acceptable and unacceptable pilot workloads. For example, the accessibility, ease, and simplicity of operation of all necessary controls is enumerated as a factor to be evaluated in determining that flight-path control and the other major crew functions can be performed by the proposed crew-complement. Each paragraph of Appendix D summarizes an additional observation of pilot performance that is to be made. Judgments by the FAA and the individual test pilots must be that each of these tasks has been accomplished within reasonable workload standards during the test flights. Numerical pass-fail values cannot be attached to these listed observations in view of the wide variety of designs and alternative possible crew-configurations. In that sense, the criteria presented do not constitute absolute measurements. Taken together, however, they provide the most comprehensive and complete definition of workload that is available.

For comparison to that of Appendix D, representative definitions of workload extracted from the open literature are presented below.

"Level of pilot workload...is determined by...the aggregate of the task demands placed on the pilot by the system...coupled with the actions required of the pilot to satisfy those task demands" (see reference 13). Chiles includes both covert and overt responses among the actions that may be required, and points out that it is difficult to determine the validity, reliability, sensitivity, and practical meaning of measured differences. This definition is acceptable because it is comprehensive, but it may be noted that the particular observations that are to be made to determine whether or not workload is appropriate are entirely unspecified.

A clinical formula for workload states that level of workload equals the sum of somatic energy expended and task difficulty multiplied by the duration of the activity (see reference 28). Using this definition it was proposed that the only near-term measurement method available was the registration of subjective assessments of workload situation through standardized interviews and questionnaires. A six-point scale, with zero representing no workload and six standing for high workload, was paired with a list of stress producing flight tasks. Many other authors have actually recorded such physical indicators as heartbeat or electrical skin resistance in attempts to quantify mission elements or design features that are assumed to decrease effort required or the accompanying psychophysiological stress (see reference 53). As far as shown in the current literature, none of these physiological or stress assessment techniques has been found to differentiate transport cockpit situations requiring one crew size versus another. It would be easy using physical indices to demonstrate a difference between a pilot who was actively engaged in a flight task as contrasted to one who was resting, or to distinguish either of these from a person who was vastly over-worked and on the point of exhaustion or disruption of coordinated performance. But as Goerres found, reasonably large and consistent differences can be obtained by simply asking pilots to rate stress situations from one to six. Surely it will be seen that the evaluations made under Appendix D include, as one element in the process, the subjective rating of the acceptability of flight-deck systems and operating environments.

According to a British survey of biological measures of workload "...flying can be assigned only to the category of very light physical work" (see reference 59). The point is made that the mental effort associated with gathering and processing information and the making of decisions is more prominent in pilot workload than is the actual physical implementation of those decisions through movement of controls. Hence, operations that are not

directly observable, as are control movements, but occur in the planning and thinking process, are of greatest importance. This is why subjective assessment by the test pilot is a particularly useful technique.

In a current study at the Massachusetts Institute of Technology (MIT), the Flight Transportation Laboratory is engaged in an attempt to evaluate alternative subjective assessment and scaling methods (see reference 61). Experiments are planned with airline crews using standard coordinated working procedures and injection of emergencies. Subjective ratings of workload will be validated against objective records of control activity, level of accuracy in flight performance, and such added scorable tasks as external target detection. The principal goal of the initial work is to discover the most valid methods of measuring pilot workload. Subsequently, the attempt will be made to illuminate presumed links between operator overloads/underloads and performance errors that can lead to accident situations. The point of mentioning this current study in this report is to highlight the fact that these well-informed investigators do not believe that the present state-of-the-art in objective workload measurement is advanced to the point that design studies and simulator tests can be substituted for proof flying, pilot observation, and pilot self-evaluation. This confirms the conclusion that resulted in writing Appendix D to FAR 25.1523. In that industry consultation process, with extensive inputs from flight deck associations, ATA, and other industry groups, it was made clear that workload must be assessed by actually trying out the ability of pilots to control such emergencies as pilot incapacitation and system failure. No responsible groups proposed "objective" or "laboratory" methods of measuring total crew member of full crew workload at that time, and the fact is that it still cannot be done today (see reference 56). The laboratory methods are useful when the goal is to perfect a design or to select between alternative candidates for specific features. But when the purpose is to assess the overall adequacy of the crew station design, with its planned pilot-complement and under the anticicipated operating conditions, it is still necessary to fly the actual aircraft and find out how well real pilots are able to control emergencies and operating difficulties.

As pointed out by Gerathewohl _et al_ (see reference 25), during the past few years, the problem of workload assessment has attained a high degree of international prominence. In addition to studies in this country, North Atlantic Treaty Organization sponsored groups have held several recent technical meetings devoted to this subject. Following from this military sequence, the U. S. Department of Defense Advanced Research Projects Agency (ARPA) called a workload meeting that was coordinated by McDonnell-Douglas in Chicago in 1978. Shortly thereafter, ALPA invited a groups of speakers, including participants in the ARPA meeting, to a symposium on "Advances in Workload Study," July 31 and August 1, 1978 (see references 6 and 27). Two advances in physiological

procedures were stressed at these meetings, the electroencephalogram (EEG) and the oculometer supplemented with a pupil dilation measurement system. The EEG has been used to relate electrical activity in the human brain to events in the performance situation but has been found to be a very diffuse measurement. It is not sensitive to the normal range of medium levels of human data processing, although it is excellent as an indicator that the subject is either asleep or awake, active or cogitating with eyes closed. Advanced data processing techniques have been applied to extract transient signals that provide a means of matching major performance events to voltage variations on the scalp (see reference 14). These variations may ultimately provide a workload index but at present are purely experimental.

The oculometer with pupilometer provides a means of recording the direction of visual fixation and a partial ability to determine whether or not the subject was concentrating on the fixation item. Again, it has been found that the pupil diameter changes are "diffuse," e.g., they are affected not only by interest in the viewed scene but also by other events impacting the subject's nervous system, such as emotional responses and physical movements that may be occurring at the same time (see reference 29).

Knowing where the pilot is looking and having an indication of whether or not he is concentrating on the instrument indication or other scene may be of considerable value to the designer who is testing a new instrument configuration. It does not, however, enable us to make a quantitative judgment as to the relation of present workload level to the remaining mental capacity. As with the EEG, the pupilometer is more a basic research and detail test instrument than a current means of measuring total workload. In concluding remarks summarizing the present state of the overall workload problem, Captain J. J. O'Donnell stated that the National Academy of Sciences should recommend a program of research on pilot workload measurement. According to O'Donnell, "the results of this long-term research will not be on line until well into the 21st century, but we also have major concerns over the workload problems of the 1980's and 1990's." (See reference 6.) The now recognized importance of improved methods of measuring crew workload in the military situation has produced support for advanced research. To perfect this research to practical applications in civil aviation will require more support and we may benefit from bringing together the various groups concerned with workload to formulate an agreed research program.

Not only is it the case with presently available technology that: a) objective measures of activity do not reveal the full pilot workload, and b) subjective measures such as pilot self-report and questionnaires have not been fully validated as methods of revealing potential advantages of flight-deck design changes, but there is an additional problem. This is that there is more to the load and effort experienced by the pilot than what happens in the

cockpit. There is a whole constellation of outside factors that influence the stress that is experienced, the fatigue felt by the pilot, and the subjective feelings that he has about his work. Among these factors are the irregular work-rest cycles with periods of absence from home and long commuting distances to points of flight origination. Unproductive delays have been documented as depressants to aircrew morale, (see reference 59) and since pilots are people, they are subject to the same emotional tensions arising from personal, social, and outside business conflicts that affect all humans. When a pilot exhibits sub-par performance, it is not necessarily a reflection of the direct stress of transport operations.

Considerable concern has been expressed from time to time that crew scheduling often results in a relatively high degree of pilot fatigue (see references 33 and 41). While the total number of allowable flight hours and duty hours does not appear to be excessive, the detailed scheduling procedures adopted under labor-management agreements may allow pilots to bid on assignments that bunch the month's flying in a small number of days. This may result in performing an entire month's allowable flying in five pairs of flights, each pair made up of a long outbound flight, followed by the mandatory layover for rest, and a long return flight. If there is difficulty sleeping on the mid-trip layover, due to odd meal and sleep hours, or to a noisy or unfamiliar environment, the pilot or entire crew may start the return trip with less than optimum rest. In these circumstances, some pilots may tend to resort to sleeping medications to insure rest on layovers and experience "hangover" effects from these medications. Should circumstances result in fatigue at the start of a flight, any additional delays or frustrations due to equipment difficulties or ATC problems could be expected to have an adverse impact on the psychological efficiency and flight readiness of the pilot in question. Check pilots and observers in the cockpit have reported that some pilot complaints of "high workload" seemed actually to be responses to frustration and fatigue buildups over such concentrated flight duty cycles. Certainly, no procedure can be expected to insure that all pilots will start all duty cycles with exactly the best amount of rest. However, one large foreign airline provides special airline hotels for air crews. These hotels schedule meal and rest cycles to fit the crew schedules, not the convenience of the larger community. Also, a brief medical check precedes each pilot going on duty, further insuring that the crew is fit for duty (see reference 45).

Flight and duty time limitations and rest requirements for crew members written into the FAR's have been unchanged for a considerable time, but there is a current notice of proposed rulemaking, Notice No. 78-3, Docket No. 17669, on this subject. That notice invites comments from the aviation community, while summarizing

initial proposals for improvements in the current regulations. In view of the changes since the existing rules were promulgated in aircraft schedules and in crew scheduling practices incorporated in individual airline agreements with flight deck associations, the Task Force expects that there will be substantial participation by pilot and industry groups in the consultative process leading to a new set of rules. Also, it is notable that one proposed simplification in the rules is to treat all Part 121 operations identically since all air carrier and commercial operations conducted in large and complex modern aircraft appear to involve the same fatigue-causing factors (see reference 20).

The motivational aspect of pilot performance is also important. This is to say that the way a person reacts to task demands depends in part on the satisfaction that he obtains through executing his responsibility and accomplishing his mission. One study found that civil airmen reported that the pleasure of completing a manual landing under restricted weather conditions gave them the greatest satisfaction as pilots (see reference 59). This may be related to the tendency observed by some accident investigators for pilots to press on with a visual approach when precision landing aids were available, are known to add to reliability, and would seem to reduce physical workload. But does precision approach reduce total workload in a way that provides the elements of challenge, the exercise of pilot judgment, and the confidence that the pilot can perform as a manual back-up or does the inherent safety of the Automatic Precision Approach warrant increased emphasis to insure satisfactory pilot motivation? These considerations may be highly important to total job satisfaction, confidence, and willingness to perform in the situation in full compliance with training directives and operating rules.

Safety requires that each member of the crew carry out his duties in the particular ways that have been worked out by the airline and presented in training. American Airlines, for example, carries this emphasis on standardization of pilot duties to the degree of requiring that the non-flying pilot call out descent altitudes in ten-foot increments from 50 feet to the ground. This, in addition to the mandatory earlier call outs, seems to require that, practically speaking, one pilot must remain glued to the instruments during the final phase of the landing. The entirely human tendency to look up and out to the runway must be suppressed in the interest of maintaining surveillance of the panel with its various information and cautionary items. But a key question is, after performing by the rules in training and check flights, does the crew-member always follow the rules? (See reference 74.) According to some authorities it is more common for an accident to result from violation, deliberate or inadvertent, of an operating rule than from an uncontrollable weather or mechanical event (see reference 69). Hence, it is necessary to insure that the normal

psychological needs of each crew member be met. Among these needs, it is important that each person have what he considers meaningful duties, a part of the activity that is valued by the other crew members, and a role that provides the satisfactions of a job well done. One cannot expect pilots or any other occupational group to exhibit optimum performance on a continuing basis simply because there is some remote danger. The person needs to be involved in a real activity and to feel that his work is valued and respected as important by his peers. Thus, a pilot for whom there is no design requirement riding along in the cockpit cannot be expected to exhibit high performance, should an emergency arise, nor can such an extra crew-member be expected to comply with rules that he considers of minor importance or mere make-work. In part reflecting this fact, the Special Air Safety Advisory Group (SASAG) report recommended that "where there is a third crew member, he should be given specific duties (see reference 64).

Among the factors that make it impossible to construct a simple, all-inclusive definition and absolute measurement scheme for pilot workload, three elements should be highlighted. First, observable eye and hand actions, or measurable control actions, signal detections, intruder sighting delays, and the like make up only part and probably not the most important part of the pilot work. We cannot measure directly the planning, problem solving, thinking and other information processing and decision-making activities that are of vital importance. Secondly, the individual state of the pilot, his rested and enthusiastic mental state, his ability and willingness to adapt to other crew members, and his level of personality adjustment, tolerance for stress and frustration, and the absence of competing, incompatible response tendencies will all be important to the way he adapts to either high or low-workload phases of a given flight (see reference 35). It is well known that errors occur in everyday activities that are well practiced. Hence, a workload that may affect 999 pilots out of 1000 in one way may have a different effect on a single pilot. Controlled tests cannot be expected to identify such rare and intricate causal chains. Finally, it is very difficult to enunciate a simple, scorable performance criterion against which to rate complex performance such as that of a pilot. Since he is doing many things more or less simultaneously, but with a coordinated flow of covert and overt actions, there is no exactly defined "correct" or ideal performance standard. Many experiments that have been conducted both in flight and in simulators have encountered this performance criterion problem. For example, elements of the airport visual guidance system have been turned off one-by-one to determine the minimum visual guidance that is essential. Pilots often have continued to accomplish apparently satisfactory landings down to a level of reduced guidance that no participant would accept (see references 42 and 11). Here the task was made harder and harder, but the recorded dimensions of the performance showed no equivalent degradation. There is no standard rule as to when the task becomes unsafe or when the probability of error

exceeds some specified value. Pushing task demands and reducing supporting systems to the point of failed performance has proved difficult in realistic, full-mission tests (see reference 10).

Such demonstrable influences from both overt measureable parameters and covert, less obvious, factors create methodological problems that have forced workload specialists in two directions. One approach is more extensively analytical, emphasizing measurable aspects of pilot performance, although recognizing the presence of covert factors in this approach, "Part Task" testing may be performed to produce needed data using test devices ranging from simple to extensive in their simulation of the ultimate application. Ultimately the workload specialist must demonstrate comparability to prior systems or infer from this analysis and measurement the total workload impact of a change in design or procedure. Alternatively, the second approach may be more global in concept but dependent upon subjective judgement in the approach, the workload specialist relies upon the ability of experienced pilots to compare the test situation to previously known situations that are accepted as constituting reasonable and proper workloads. The workload specialist must assume pilot judgment as representative and consistent in the presence of variations in situations as well as in pilot experience, skills, and performances.

A typical analytical approach uses the definition: workload, in percent of time, equals the time required, divided by the time available, times 100 to convert to a percentage (see reference 10). Before a calculation can be made with this formula it is necessary to know two things, what tasks are required and how long each takes. The data may be produced by analysis or prior relevent data or by simulation of the influence of covert factors that are taken into account. Detailed procedures have been published for doing this work, and the ultimate summarization covering many possible flight situations and alternative flight events is made in a digital computer that has the capability to process huge numbers of possibilities and combinations. The resulting output is expressed in numerical form for each crewmember at each point during the flight. It has the precision of numbers and the flexibility to permit recalculation for a large variety of flight-deck design features and operating rules and will be conservative since in the real world the tasks will often be performed nearly simultaneously (see reference 55).This analytical method has the flexibility to continuously support airplane design, development, and certification from early pre-design through flight confirmation. The results can be updated during the evaluation of a given design, and refined results can be used as an initial base line for the next development. What it lacks is a direct access to the non- observable events taking place inside the pilot, where may reside the antecedents of that very low-probability event, a critical error of omission or commission.

Pilots have shown the ability to sustain measured control performance in increasingly stringent conditions, such that recordings showed little or no effects of increasing task difficulty. Alternative methods of approach to workload for such conditions are used, two of which follow. The so-called secondary-task method has been employed (see references 9 and 37). Usually, an artificial task, anything from mental arithmetic to pressing buttons to turn off random light signals, has been added to the usual pilot duties. The subject is told to fly the simulator or aircraft first, and when he has time left over to perform the secondary task. Presumably, a light pilot workload will permit accomplishment of a large number of the secondary task items, while a heavy pilot workload will require that full attention be given to flying with no secondary items completed. An alternative approach to workload quantification has been proposed using the "adaptive" simulator paradigm (see references 16 and 37). If this system were used to test the workload in a particular cockpit configuration with a particular flight scenario, the computer would be programmed to make flight tasks increasingly difficult (by adding rough air, instrument errors, ATC workload, etc.) to the point that the crew was barely able to stay within predetermined limits of precision in holding altitude, course, and speed. If performance deteriorated below those limits, the computer would automatically ease the task. The result of such an adaptive interaction between pilot peformance and task difficulty is a numerical score stating that this particular crew can meet requirements up to task difficulty so and so, but fails to meet requirements at greater task difficulties. After a sample of such tests, the cockpit configuration might be changed to incorporate additional automation, improved displays, or other features thought to reduce pilot workload. Then the tests would be repeated to discover whether or not the same crews could show acceptable flight plan following with greater computer generated task difficulty factors.

Both the secondary task technique and the adaptive simulator technique have the advantages of providing numerical scores on pilot performance in test cockpits. Both procedures are being studied and tested here and abroad as possible means of evaluating workload in improved aircraft, the effect of improved ATC environments, and training proficiency (see references 45 and 53). With either procedure, the crew can be loaded to the degree that a scorable performance decrement is shown. There are, however, obvious disadvantages in the artificiality of manipulating crew duties in this way. It is quite difficult for a person to assess his momentary workload and decide whether or not he has time to turn to a secondary task. One pilot may concentrate his scan on the flight instruments and ignore the demands of the secondary task, but this does not prove that in an emergency he could not revise his scan and divert attention momentarily to a genuine flight requirement. Similarly, the adaptive simulator approach assumes that the flight

performance limits that have been adopted are meaningful. In actuality, the pilot exercises judgment in determining the appropriate priority for his actions depending on the immediate situation. Hence, when two pilots react differently to task demands, it is not realistic to assume that one was right and one was wrong, one beyond his performance limits and another still retaining spare mental capacity. As with the analytical approach, the experimenter would have to see inside the individual's thinking process and determine why one held altitude so tightly while another concentrated on another aspect of flight. Nonetheless, these synthetic test methods are expected to find more applications in future workload studies.

In summary, it may be said that crew workload measurement techniques are rapidly evolving and that these techniques in conjunction with the use of "base-line" designs which have been operationally proven, and the continuously evolving FAA requirements provide an adequate certification basis, as evidenced by the steadily improving airline safety record.

THE CURRENT DESIGN PROCESS

Since there is no single valid and accepted method of assessing the impact of particular designs on total crew workload, the manufacturers rely upon previous designs, proven in operational service, to form a satisfactory baseline for their later flight deck designs. Each major aircraft manufacturer has crew systems groups that are engaged in developing both analytical-computational and real-time design evaluation methods. At this time an extensive list of computer programs has been developed, particularly by Boeing Commercial Airplane Company and Douglas Aircraft Company, and parallel analytic work is conducted by NASA and other research and development groups engaged in both civil and military aircraft development and evaluation (see reference 43).

The second direction that has been followed in recent design and test activities utilizes real pilots and actual real time flight duplications for input data, while relying on pilot judgments for results. In this method the effort is made to include as realistic a flight environment and scenario as is possible at the particular stage of design progression. Thus, if the aircraft is in the proposal stage, paste-on mockups may be the most realistic flight deck environments that are available. If the program is continued on to fruition in a production model, the real-time tests will progress to more functional mockups, then to part-active, and finally to full-performance simulators. Ultimately, prototype test aircraft will be "flown" starting with a simulator device, leading to an aircraft that can be taxied, and culminating in actual flight-test (see reference 30).

As an example of the use of an analytic comparison of a component assumed to reduce workload with a conventional component, Douglas Aircraft reported the numerical time-saving found in using a boom microphone in place of a hand-held type. A computer run selected out all the times associated with picking up a mike, bringing it to the talk position, and returning it to storage. The tabulated results showed that the first officer saved a small but significant part of his time in the busy minutes during descent and approach. The conclusion was that any aircraft operator now using a hand mike and having a copilot who is complaining of overwork during approach could reduce this workload by changing to the boom mike (see reference 10). It would not be argued that a computer test of this sort reveals whether or not workload is critically high in an absolute sense, or indeed that error potential is excessive for this crew position under the hand-held microphone condition. Rather, the weight of the conclusion falls to the point that an assumed improvement has been confirmed, and an approximation of quantification has been attached to that confirmation.

At once, it can be seen that flight tests, whether on the ground in mockups and simulators or in the air, have both advantages and disadvantages as compared to the analytic, part-task computations. The principal advantage is in realism and validity, while the disadvantages include the inability to sample a wide variety of design alternatives and the impracticality of replicating tests to produce assurance that a given design will meet all possible variations of requirements and all pilot differences. It has been the practice in major commercial aircraft development efforts for the manufacturer to use both analytic and full-task simulation methods because of the potential advantages of each.

FAA regulations require only a minimum of cockpit standardization, relating mainly to the placement of primary flight instruments in the "T" pattern, and certain distinctive coding and placement of critical controls. Other design guidance in the regulations centers on performance standards such as visibility. The airlines, in conjunction with the manufacturers, have agreed to go far beyond the standardization requirements, apparently in the interest of reducing costs for training and parts replacement (see reference 31). Hence, when a new flight deck is considered, it is invariably a derivative of an existing cockpit design. Certain components may be proposed as replacements for the conventional items, and some degree of rearrangement may be contemplated. New avionics systems may need to be fitted into existing panels, and newly automated systems may replace current indicators and controls. The general configuration of the flight deck is likely to remain quite familiar in the new model, however, so that it is the case that a B-707 cockpit has many similar features to other Boeing cockpits. Similarly, the cockpits produced by other manufacturers have both a "family" resemblance and a strong similarity in basics across company lines.

As a result of this evolutionary characteristic of the flight deck design process, there is always a "reference" flight deck design, by which is meant a conventional aircraft that has been through the test of airline usage and in which many pilots have strong experience. Since the new design represents an evolution, improvement attempt, or other derivation from this reference flight deck, the potential exists to make direct comparisons. Thus, while the available workload measurement techniques do not provide the capacity to place precise numbers on all the relevant design features in reference to error or accident potential, these techniques do provide the required means to compare the new proposal to a known quantity; an accepted "safe" cockpit proven by operational experience to have satisfactory workload characteristics for the current airline environment.

While a subject pilot, after studying a new component or arrangement and exercising it in practice flight scenarios, may not be able to grade that design in workload units, he can say with reliability and confidence that it is or is not easier to see or use than a reference design. These "better" or "worse than" judgments, if corroborated by a reasonable sample of pilots over various assumed flight regimes, provide substantial evidence that workload is or is not reduced by the innovation.

Similarly, while a workload estimate computed on the basis of eye or hand dwell-times may not be acceptable as an absolute measurement to be compared to a standard, there is a substantial value in measurements that can be obtained early in the design cycle, before a full-performance simulator has been developed. Once the alternatives have been narrowed down to a manageable set, it is the usual practice to mockup or simulate these principal candidate configurations. At that stage of the design process, the manufacturer turns to his cadre of flight-test pilots for initial judgments. Since aircraft manufacturers provide training for airmen of aircraft purchasers, there exists a training department at each company with specialists in defining standard crew duties and pilot performance standards. Along with the flight-test pilots, the training experts are called in to evaluate the features and arrangements that have been altered in the new cockpit. At later stages of the new aircraft program, groups of pilots from outside the company are generally brought in, including committees from airline pilot associations. Ultimately, the manufacturer settles on a final flight-deck design, but it should be understood from the preceding summary that this is the culmination of a long and deliberate design process.

On occasions a new aircraft or a new member of an existing production series, will have relatively few changes in the flight deck. In the switch from narrow body to wide body design, a number of years had intervened between the design of the earlier and later transports. Hence, there were significant avionics and instrument changes to be evaluated. Also, the introduction of the DC-9 and the B-737, with flight decks laid out for two pilots, while earlier transport aircraft produced by the same manufacturers had mostly used three crew members, occasioned major automation and crew duty simplifications. In all of these instances, the design process was drawn out over a period of years, many alternatives were evaluated, and a variety of types of workload tests were employed. It is not true to assert, as have some critics of the industry, that the crew station design was fixed at the outset of the aircraft program (see reference 2).

Appendix IV to this report contains illustrations of the schedule and varieties of crew-station design tests that were conducted in the case of representative transport aircraft developments.

THE AIRWORTHINESS CERTIFICATION PROCESS

The context in which the federal authorities make a determination of the flight-crew complement for a proposed airline aircraft is the airworthiness certification proceeding, which is conducted by the regional office in whatever district of the country the manufacturer is located. The proceedings, in which the manu facturer presents design information, demonstrates regulatory compliance in the production and test of components, systems, and completed aircraft, and participates with the FAA engineering and flight-test people in both in-flight and static tests and evaluations, are conducted by the FAA operating out of a particular regional office. The great majority of these type certification proceedings concern aircraft structures, power plants, electronic, hydraulic, and pneumatic systems, and the safe operating limitations of the aircraft. These are not in any sense "adversary" proceedings but rather constitute an independent check and verification that the aircraft complies with the rules and regulations that have been developed over a long period of aircraft operating experience and that novel features and unique systems or properties are safe and reliable. Such determinations by the FAA, or related actions by other government bodies, are practical, not ideal or theoretical matters. They require a degree of adjustment to the uncertainties of the real world.

A system can fail in an infinite number of ways, and perfection is not of this world. The designer, in accordance with the doctrine of fail-safe and with FAA approval, provides for this eventuality by designing alternate means of control for the failure of any vital system. Hence, a government review of a new design and even an extensive test series will not prove that nothing can ever go wrong with the new aircraft, but rather that the failure of any essential system will not prevent safe completion of the flight. The point of airworthiness certififcation is not, then, to guarantee that the aircraft is perfect in the sense of safety, but rather to guarantee that an independent review has been made of the evidence on regulatory compliance, soundness of design and manufacture, and operating rules, and the capability of managing system failure in a safe manner.

The process of engineering design and test of new aircraft has been greatly developed in recent decades, and the result of this improvement is evident in the reduction of "learning curve" accidents and early design retrofits in later model aircraft. One mark of the technological improvement is found in the practice of constructing a simulator, sometimes called an "iron bird," for preproduction testing of flight control and hydraulic systems. Following this procedure, it is usual for an aircraft manufacturer to first build a partial mockup which has all or

most of the important moving parts of a real aircraft and ties them together with the real harnesses, cables, and tubing. This allows control surfaces to be moved against realistic forces, and systems such as the electrical, pneumatic, and hydraulic components may be cycled to determine the appropriate service and replacement schedules and any weak links in operating chains. It is usual to operate such test rigs through an approximate life cycle of an aircraft, a test program requiring many months and often resulting in literally hundreds of design improvements and strengthening of parts and systems. In addition to systems integration testing of this sort, virtually every portion of the aircraft design that deviates from past accepted practice in concept or operation is subjected to additional stress-testing to establish failure limits. All of this preproduction testing, along with highly developed quality control standards in manufacture, and both manufacturer's trial operation and prospective customers demonstrations, lead to a great deal of design assurance in the case of new or redesigned aircraft. FAA airworthiness proceedings are simply an independent verification of compliance and adequacy.

As noted above, determination of flight crew complement is only one aspect of airworthiness certification. As with other aspects, the focus is upon compliance with regulations that have previously been applied to other aircraft, and upon added specific examination of the new flight deck. Since the determination of the various aspects of airworthiness represents a set of judgments, as opposed to an absolute set of measurements, the process would seem to be nearly impossible of reasonable accomplishment were it not for the fact that a body of experience exists from prior designs and airworthiness actions. This makes it possible to compare the new design to existing designs of proven adequacy and to focus on the specific ways that the new design differs from the usual practice. This is to say that airworthiness proceedings on the very first generation of transport aircraft could not possibly have been conducted with the success that is demonstrated today. Not enough was known then about the safety and correctness of various provisions and ways of operating. Engineering and flight-test personnel today, operating from the base of knowledge that they have accrued concerning other aircraft, can make informed judgments about design features and can compare various aspects of a new aircraft and other models. In this way, a group of pilots can operate a new aircraft or pre-production simulator and provide evidence that certain individual systems or overall flight handling in particular regimes is or is not equivalent to some specified other aircraft, or is superior or inferior in handling ease or difficulty to some comparison system or aircraft. Because of the background knowledge of such pilots, credence can be placed in judgments of this kind, although no one would argue that this constitutes "absolute" measurement.

In the case of crew complement determination, the final decision is reserved until the aircraft has been flown by a panel of experienced pilots, particularly in the case of any new aircraft that is designed for operation by a smaller crew than that employed on earlier or comparison aircraft. Broadly speaking, more assurance is derived from actual flight test than from earlier simulator tests or other synthetic or computer model procedures, although these may have been conducted in direct side-by-side comparisons (see reference 56). The problem encountered in actual certification proceedings, as mentioned before, is that the preliminary decision to go ahead with the design of a new flight deck must be made long before there is an actual aircraft for flight test (see reference 51). Hence, it is absolutely necessary to utilize other, less obviously credible methods of collecting pilot workload data. The saving feature of this dilemma is that the flight deck of the new aircraft is not something designed _de novo_. Rather, it is, as discussed above, an evolution or revision of already existing and well-proven cockpits. In the development of the B-737 two-man cockpit, for example, baseline data were available on the number of duties performed and the time required to conduct those activities by the pilot and first officer of the comparison B-727, an already existing three-man flight deck. Hence, the crew station design team set out to simplify crew duties to the point that it could be demonstrated that the new aircraft would require less work, or at least no added work, when comparisons were made with an aircraft whose pilot workload had already been proven satisfactory in actual service. Direct comparisons made via both computer generated time-and-motion analyses and subjective evaluations by representative pilot samples provided substantiating evidence, even though no full-performance cockpit was available in either a training simulator or an actual aircraft.

Appendix IV to this report consists of illustrative schedules, documents, and sample crew-station tests that were conducted during the flight-deck design and aircraft certification cycles of the two major two-crew aircraft, the DC-9 and the B-737, with additional materials relevant to subsequent certification efforts on the DC-10 and B-747.

The first striking aspect of these records is that studies of crew workload and the impact of improved flight-deck facilities began about three years before actual certification. Workload was studied both as a function of alternative systems in the new flight deck and as a comparison with a reference aircraft. Computer programs were used in an extensive series of calculations for such sub-studies as external visibility and control placement for optimum reach. Mockups and simulators were used for pilot evaluations and simulated operations with side-by-side comparisons.

This work was described to the Task Force, and remaining mockups and simulators were examined on task force visits to the manufacturers. Regional personnel described to the Task Force the involvement that they had as observers and particicipants in extended test series. In the opinion of the Task Force, the workload evaluation efforts conducted in connection with the design and certification programs were thorough, competent, and up-to-date in methods.

Airworthiness determinations must be practical, real world decisions partaking of the character of other regulatory processes which must make reasonable trade-offs between progress in technology and assurance of public safety. If every new development were held back until a degree of absolute certainty were reached about all possible safety aspects, progress would be reduced to an unacceptable level. On the other hand, introduction of a new transportation component must be the subject of careful and independent safety evaluation. The record of civil aviation, and particularly domestic U.S. certificated air-route carriers, appears to bear out the soundness of the present regulatory system. At the same time, past failures to anticipate specific hazards are recognized as events that have occurred. It is generally accepted, however, that there has been a declining frequency of type groundings and a general improvement in the reliability of vital aircraft systems. In this connection, it may be noted that Captain R. C. Gerber, one of America's best known airline pilots and former chairman of ALPA's Air Safety Committee, has pointed out the great reduction in hull attrition and engine shutdowns during his career spanning the Sikorsky flying boats to the B-747 (see reference 26). This record indicates that progress has been made in engineering design and test, and the Task Force believes that progress has been made as well in improving airworthiness certification methods and procedures.

In view of the safety gains that have been made, the Task Force recommends that the FAA authorities directly concerned with airworthiness certification confer and document uniform guidelines that have been successfully employed in past certication of aircraft. Publication of a standard manual would make available to the larger aviation community the methodological insights that those regions that have been most concerned with aircarrier aircraft certifications have developed. Further, such a manual would tend to insure that future certification proceedings and attendant records would be organized in a uniform fashion regardless of the location of the responsible region. At one time, all the major aircarrier aircraft manufacturers were located within the area of the Western Region of the FAA. Naturally, a high degree of competence in planning and conducting such activities was developed in that office. Now, however, a major portion of the responsibility resides with the relatively

new Northwest Region, and other potential manufacturers report through the Southern Region or other Regional Offices. Hence, there appears to be substantial potential benefit from publication of guidelines for uniform national certification procedures.

During oral briefings by the Task Force on its findings, questions arose that made it apparent that not everyone understood the process of reasoning that led up to the recommendation that the certification procedures be codified in standard, national form. Hence, additional discussion of the base for this recommendation will be summarized.

First, it is recognized that the technology of establishing workload measurements has moved rapidly, and the industry has increased its use of this technology. A substantial body of computer programs has accrued in the course of recent aircraft design programs and government sponsored research and development efforts. This field of activity, then, is more complex today and requires more concern with the selection of methods and techniques that may be most appropriate for particular aspects of workload study.

In addition, the amount of certification experience has varied between different regional offices of the FAA. At the same time that human-factors aspects of aircraft design and operating practices have come to be recognized as being of increasing importance, some regions have had far greater opportunities to stay abreast of the rapidly developing technology in this specialized area. Other regions have had less reason to deal with the more complex multiple-crew cockpit developments and, as a result, would be less well prepared to conduct a program of review of a manufacturer's human factors studies leading up to development of an FAA flight test program.

In the case of the most recently developed aircraft that were designed for two-man crews, the DC-9 and the B-737, extensive programs of workload evaluation and of comparison demonstration were conducted by the manufacturers. When the time came to design the B-747, the manufacturer elected to follow similar workload measurement procedures, although in this case there was no reason to expect that minimum crew complement would become a special concern, due to the conventional three-pilot layout that was adopted from the start. With the DC-10 and L-1011 programs, the Western Region obtained continuing experience with the later workload measurement technical developments.

The experience of the Western Region has not been fully paralleled in other parts of the nation. Even in those more experienced regional offices, the Task Force found that there was not a written, set procedure for insuring that future Appendix D regulatory

compliance programs would be handled in different cases on an equivalent basis. There is, naturally, a desire on the part of the manufacturer to expedite the compliance demonstration process, to initiate it as early in the program as possible, and to restrict actual flight-test, with all its attendant costs, to the minimum that will be acceptable. With evolutionary aircraft development programs, the manufacturer may feel that his new aircraft is a derivative model, with no possibility of not representing a lowering and further improvement in pilot workload, when it is compared to the earlier reference flight-deck. Such issues as how much functional and reliability flight-test is required for pilot workload documentation, who should fly the aircraft in these tests, and the role of computer generated and other analytic data in supporting the conclusions from a flight-test series may be subject to alternative resolutions.

The Western Region has drafted an outline procedure for certification, and it appeared to the Task Force that this raised the question of whether it would be more appropriate to have a national, rather than a regional procedure. Development of an FAA-wide certification procedure handbook or manual would serve two purposes. First, it would provide guidelines to the regional authorities that would aid in resolving key issues and in arriving at an acceptable pilot-workload documentation plan. Second, the publication of such a guidance document would insure industry awareness of the type and volume of data that is normally required, so that the manufacturer could plan his demonstration and test efforts more realistically. National standardization, in the sense of guidelines, not rigid experimental plans, would make it feasible to draw on the best knowledge currently available in the government and the outside aviation community to insure up-to-date, equitable, and reasonable handling of sensitive issues in future crew-complement determinations.

ACCIDENT RATES FOR TWO AND THREE MEMBER CREW AIRCRAFT

ALPA has provided (see reference 50), a summary of airline accident experience, and made the assertion that statistical analysis of appropriate subsamples of the tabulated accidents revealed a disproportionate number of passenger and crew fatalities in certain two member crew aircraft. This Task Force undertook a review of accident data and a conclusion as to the relation between crew-complement and accident rates. This effort included both an extensive study of the total accident experience over the period of time that the two member and three member airliners have operated in a common environment, and review and evaluation of the open literature of studies of causal links between pilots and aircarrier accidents.

Both U.S. and I.C.A.O. reports demonstrate that accident rates have declined in the jet era (see references 1, 7, 57, 62, 72). Earlier jet aircraft had higher initial accident rates than did jet aircraft that were developed later. Paralleling this improvement in safety over successive model introductions, safety rates improved over time with individual aircraft types. Thus, the jet fleet shows generally improved safety over its twenty-plus years of experience, with part of the credit attributable to improved aircraft, and additional credit due to improved supporting systems. Beyond this time-trend, an additional factor that makes it tenuous to compare raw accident rates between different aircraft types is the differential usage of long range and short range aircraft, and the consequent differences in airports, weather environments, and other variables. Furthermore, depending upon whether rates are expressed per million departure cycles, per million hours flown, or per million passenger miles-flown, it is possible to alter somewhat the appearance of any particular comparison.

A technique that the Task Force recommends for improving the meaningfulness of inter-type comparisons is herein called "normalizing." This process consists of eliminating accidents that cannot reasonably be attributed to the aircrew, (principally enroute passenger and cabin attendant injuries caused by turbulence and additional accidents that occurred while the aircraft was on the ground, such as a deplaning passenger slipping on an air-stair door, or a ground handling truck running into a stationary aircraft.) None of the normalizing operations carried out in the Appendix tables had the effect of making two-crew aircraft appear superior in accident incidence. The principal effect was, in fact, to reduce the accident rate attributable to long haul, high passenger capacity aircraft, for which these miscellaneous, non-pilot involvement accidents would obviously be more frequent.

Authorities are agreed that, in relation to the volume of air travel, the number of fatalities in scheduled airline service is declining worldwide and that U.S. fatality rates are generally superior to other parts of the world (see references 15 and 39). At the present time, the number of airports equipped with precision approach aids and improved terminal area ATC systems is increasing, and more and more general aviation aircraft are insuring their participation in the cooperative ground control system by operating airborne radar transponders. Hence, there is every reason to anticipate that the future operating environment will be characterized by significant added safety enhancements. Recognizing this, most authorities confidently predict continued improvements in the already excellent safety record of certificated air-route carriers.

The specific tabulations made by the Task Force are set forth in detail in Appendices I, II, and III to this report. The computations cover the full 10-year accident experience 1967 through 1976, for the important two member crew aircarrier aircraft, the DC-9, the B-737, and the BAC-1-11, and comparison three member crew aircarrier aircraft, the B-727, and the DC-8. Further included are those B-737's operated by crews of three. As will be seen from a careful perusal of the data, all of these computations refute the statement that there is an excess accident rate experience with two member crew aircarrier aircraft.

Specifically, the DC-9 and Boeing 727 accident rates were compared (See Table 1). There are over 13 million departures for the 727 and over 10 million for the DC-9 in regular certificated U.S. aircarrier service in the ten-year sample. Hence, sample size is deemed adequate. Altogether, these two aircraft have experienced 127 total accidents. Eighty-six (86) involved 727's and 41 involved DC-9's. It has been computed on the basis of all risk factors being equal that the DC-9 would have experienced more than 41 total accidents. A chi square statistical test on all these differences between actual and equivalent computed accident frequencies is statistically significant beyond the normal conventions of statistical reliability. When accident experience of the two airliners is normalized by eliminating turbulence accidents and certain other events that cannot reasonably be charged to the air crew, such as deplaning passengers slipping on air stairs, the number of accidents is, of course, reduced, and statistical tests show no significant differences. The same is true of tests made on fatal accident statistics. Hence, in this key comparison of a two member crew aircarrier aircraft and a three member crew aircarrier aircraft, the only significant difference in accident experience is one that favors the two member crew aircarrier

aircraft. Further, the other two member crew aircarrier aircraft, the BAC-1-11 and the two-man crew Boeing 737 operations, have outstanding safety records.

All of the statistical tests that attain conventional levels of confidence do, in fact, show higher accident experience in three member crew aircarrier aircraft. This higher accident rate, particularly in the case of the DC-8, appears likely to reflect factors such as seating capacity, average stage-length, and year of model introduction, rather than any current difference in accident risk.

Table 1 summarizes the basic data on U.S. aircarrier accidents, 1967 through 1976, for five aircraft types. The aircraft types selected for inclusion are the principal turbojet aircraft certificated for operation by two member crews, (the DC-9, B-737, and BAC 1-11), plus two of the antecedent manufacturers' aircraft certificated for three member crews, (the DC-8 and B-727). In addition, those operations of the B-737 that have been conducted in accord with the labor-management agreements between ALPA and certain airlines to have a third flight-deck crew-member on board are listed in a separate column.

Departures have been taken as the best index of flight activity because of the fact that accidents, and more particularly "pilot error" accidents, occur most often in the departure and arrival phases of flight. Enroute stages are more likely to show a low accident incidence and a concentration of turbulence accidents among the few that do occur. Total number of accidents for each classification is shown immediately below departures by the type aircraft, and then both "normalized" and fatal accident subtotals are shown. Since normalizing eliminates classes of accidents that cannot reasonably be attributed to crew actions or inactions, those totals are considered to reflect the maximum potential for crew involvement in accident incidence. Fatal accidents are still fewer in number, and because of their great importance, no reductions have been made in fatal accident totals through the so-called normalizing process. Finally, rates based on aircraft departures are shown, and calculated (hypothetical) equalized numbers of accidents are shown on the final three lines.

By hypothetical equalized numbers it is meant that if we knew that all types had equal likelihoods of experiencing accidents, considering the amount of departures over the ten-year period, this is the calculated number of accidents that would have befallen each aircraft type.

TABLE 1
U. S. AIRCARRIER ACCIDENTS (1967-1976)
FOR FIVE AIRCRAFT TYPES

PARAMETER	B-727	DC-8	B-737 2M	B-737 3M	DC-9	BAC111	TOTAL
Departures (in millions)	13.386	2.473	0.644	2.568	10.007	1.483	30.561
Total Accidents	86	55	1	9	41	7	199
Normalized Accidents	54	16	1	7	32	2	112
Fatal Accidents	12	4	0	1	11	1	29
Total Accident Rate	6.42	22.24	1.55	3.50	4.10	4.72	6.51
Normalized Accident Rate	4.03	6.47	1.55	2.72	3.20	1.35	3.66
Fatal Accident Rate	0.90	1.62	0	0.039	1.10	0.67	0.95
Percent of Total Departures	43.8%	8.1%	2.1%	8.4%	32.7%	4.9%	100%
Hypothetical Total Accidents	87.2	16.2	4.2	16.7	65.1	9.8	199
Hypothetical Normalized Accidents	49.1	9.1	2.4	9.4	36.6	5.5	112
Hypothetical Fatal Accidents	12.70	2.35	0.61	2.44	9.48	1.42	29.00

TABLE 2
SUMMARY OF ACCIDENT DATA
BY NUMBER OF CREW MEMBER FLYING AIRCRAFT

AIRCRAFT	2-CREW	3-CREW	TOTAL
Departures (in millions)	12.134	18.427	30.561
Total Accidents	49	150	199
Normalized Accidents	35	77	112
Fatal Accidents	12	17	29
Total Accident Rate	4.04	8.14	6.51
Normalized Accident Rate	2.88	4.18	3.66
Fatal Accident Rate	0.99	0.92	0.95
Percent Departures	39.70%	60.30%	100%
Hypothetical Total Accidents	79.0	120.0	199
Hypothetical Normalized Accidents	44.5	67.5	112
Hypothetical Fatal Accidents	11.5	17.5	29

Table 2 then further summarizes all these data into a head-to-head comparison of accident incidence data for two member crew and three member crew turbojet aircraft. The entries are, as will be seen from the totals column, the same ones used in Table 1.

We know, of course, that complex events never occur in exactly equal numbers based on exposure. Random factors will enter into the determination of any large sampling process, so that realistically we never expect the numbers of accidents to come out exactly even in a given period. The main function of conventional statistical difference testing is to allow us to assign a probability estimate to the chance that our obtained differences are real, i.e., that they reflect differences in the real likelihood of accidents, not merely the expected chance variations in a limited series of observations. In doing this the most accepted technique is the one called "Chi Square," details of which may be found in any current statistics reference work. Further, it should be mentioned that it is conventional in difference testing to say that a difference between a hypothetically equal rate and an actual sample difference is "statistically significant," i.e., believable, if the probability of obtaining an equally large or larger difference through sampling factors or other irrelevant influences is not more than one in twenty ($p = 0.05$ or less).

Chi square statistics were run for all aircraft types, for two versus three crew member aircraft and the DC-9 versus B-727. Analyses were not run for differences in fatal accidents by aircraft type or by two versus three member crew complement for the following reasons. The numbers of fatal accidents for several types, see Table 1, were too small, e.g., 4, 1, and 1, to permit calculation. Also, in the case of the pooled two versus three member crew aircraft, see Table 2, the hypothetically equal and actually recorded frequencies were so close that it was apparent that the difference would not be statistically significant (12 versus 11.5 and 17 versus 17.5 for fatal accident totals).

In the next section, the resulting statistical calculations are summarized. Comparing across all of the selected aircraft types, there was a statistically significant difference by total accidents, but not by normalized accidents. Although all of the possible individual comparisons were not tested statistically, it is apparent that the DC-8 accident rate is high, meaning that fewer accidents would have been computed on the equality assumption, and that the DC-9 accident rate is low, with fewer actual accidents than would have been computed on the same assumption. The DC-8, of course, carries more people, thereby having the greater chance that someone might be injured on any particular flight. Further, the DC-8 flies longer stage-lengths than the average turbojet, and this means that for an average departure there is more time for someone to be

injured thru an in-flight turbulence encounter or something to go wrong. Finally, the DC-8 was introduced earlier in the jet period, and it is known that accidents were more frequent in the early period of jet service in earlier years. In the book, The Safe Airline, reportable accidents for million hours are shown for early turbojet transports such as the Caravelle, B-707/720, and DC-8, as well as for later turbojets such as the B-737 and DC-9. In all cases, the accident rate during the first million hours of flight was higher for the "first generation" aircraft. The later aircraft had first million-hours accident rates more similar to the improved, second million-hour rate of the early aircraft. By the fifth million-hours, the early aircraft were showing accident rates nearly equivalent to those of the less experienced later aircraft (see reference 57). Following this line of reasoning, it is apparent that a finding of a difference in total accident rates for different aircraft types can be explained on a rational basis by factors unrelated to "pilot error." At the same time, it is clear that these tabulated rates and statistical tests do not support an assumption that the factor of two versus three crew members on the flight deck is one of the factors associated with differential accident experience.

Finally, for the DC-9/B-727 comparison, there was a statistically significant difference for total accidents with the DC-9 having a lower accident rate than the B-727. The normalized accident and fatal accident rates were not statistically different.

STATISTICAL ANALYSES

1. Total accidents: by aircraft type

$$X^2 = \frac{(86-87.2)^2}{87.2} + \frac{(55-16.2)^2}{16.2} + \frac{(1-4.2)^2}{4.2} + \frac{(10-16.7)^2}{16.7} + \frac{(41-65.1)^2}{65.1} + \frac{(7-9.8)^2}{9.8}$$

$$X^2 = 0.016 + 92.928 + 2.438 + 3.550 + 8.922 + 0.800$$

$$X^2 = 108.65 \quad (df = 5) \quad p = \angle .001$$

2. Normalized accidents: by aircraft type

$$X^2 = \frac{(54-49.1)^2}{49.1} + \frac{(16-9.1)^2}{9.1} + \frac{(1-2.4)^2}{2.4} + \frac{(7-9.4)^2}{9.4} + \frac{(32-36.6)^2}{36.6} + \frac{(2-5.5)^2}{5.5}$$

$$X^2 = .489 + 5.232 + 0.817 + 0.613 + 0.578 + 2.227$$

$$X^2 = 9.956 \quad (df = 5) \quad p = \angle .10$$

3. Total accidents: two- versus three-man crews

$$X^2 = \frac{(49-79)^2}{79} + \frac{(150-120)^2}{120}$$

$$X^2 = 11.392 + 7.500$$

$$X^2 = 18.892 \quad (df = 1) \quad p = \angle .001$$

4. Normalized accidents: two- versus three-man crews

$$X^2 = \frac{(35-44.5)^2}{44.5} + \frac{(77-67.5)^2}{67.5}$$

$$X^2 = 2.028 + 1.337$$

$X^2 = 3.365 \quad (df = 1) \quad p = < .10$

5. Total accidents: DC-9 versus B-727

$$X^2 = \frac{(41-54.3)^2}{54.3} + \frac{(86-72.7)^2}{72.7}$$

$X^2 = 3.258 + 2.433$

$X^2 = 5.691 \quad (df = 1) \quad p = < .02$

6. Normalized accidents: DC-9 versus B-727

$$X^2 = \frac{(32-36.79)^2}{36.79} = \frac{(54-49.21)^2}{49.21}$$

$X^2 = 0.624 + 0.466$

$X^2 = 1.090 \quad (df = 1) \quad p = < .30$

7. Fatal accidents: DC-9 versus B-727

$$X^2 = \frac{(11-9.84)^2}{9.84} + \frac{(12-13.16)^2}{13.16}$$

$X^2 = 0.137 + 0.102$

$X^2 = 0.239 \quad (df = 1) \quad p = > .50$

Since initial release of the foregoing summary of the Task Force accident rate analysis, the issue of a possible disproportionately large incidence of pilot-error accidents in certain two member crew aircraft has not been re-raised. Hence, it is not considered necessary here to elaborate on the simple finding that examination of overall, long-term accident rates reveals no such safety disadvantage to two member crew aircraft. For the reasons mentioned at the outset of this section, comparing accident rates between different aircraft types that tend to be operated along somewhat different routes, by different airlines, and exposed to different weather and terminal control aids has somewhat the character of comparing apples and oranges. The Task Force members believe, however, that the smaller transports, which are more likely to be manned by a crew of two, are operated in the more stringent environment, one with more short-stage lengths, more landings per hour, and service to less well-equipped airports. Hence, the statistical outcome that shows no higher accident incidence in these aircraft is doubly credible as indicating that the two member crews are operating safely.

One specific issue had been raised to the effect that two member crews were less able to scan the skies for possible collision threats and, hence, were subject to a higher incidence of mid-air collisions. As stated by the ALPA, in the four years 1967 through 1971, there were six mid-air collision accidents, each involving a DC-9 and a non-aircarrier aircraft (see reference 48). Of the six, the NTSB found that in only two cases did the crew of the DC-9 clearly have the capacity to see and avoid the other aircraft. One of these two accidents was a two-crew member DC-9; the other had two fully rated captains and a first officer who were given a traffic advisory by air traffic control and were presumably making every effort to detect the other aircraft (see reference 46). The NTSB pointed to the mixing of controlled and non-controlled traffic in the terminal area as presenting a significant accident potential, and the FAA recognized this limitation of the see-and-avoid concept and has instituted corrective improvements in the ATC system. A number of improvements have been made in FAA procedures, more aircraft are beacon equipped, and positive control areas have been expanded. We cannot place exact weights on the various changes, but it is notable that there have been no further mid-air collision catastrophies involving a DC-9 in over seven years, although the number of DC-9 operations has continued at a high rate.

The only reasonable conclusion that can be drawn from the accident statistics reviewed by this Task Force and summarized in Appendices I, II, and III to this report is that at present, two member crew airliners are being operated in as safe a manner as three member crew airliners.

TASK FORCE MEMBERS
SUMMARY

Rapid technological change has characterized turbojet transport aircraft in recent decades, and at present interest and controversy center on cockpit development and applications of automation. The pilot's job has changed, but he is far from having been engineered out of the control loop. Consequently, the continued improvement in cockpit designs and intelligent uses of automation require more human performance information useable in allocating functions between men and machines and information that enables a determination to be made that some system change or presumed improvement does actually aid the pilot, rather than saddle him with additional monitoring functions and additional responsibilities to revert to manual control in case of equipment failure. Responding to this need for more human performance data, much effort has been devoted by both government and industry to improve the objectivity and the validity of the test methods and design techniques that are used.

Compatibility of a cockpit design and the pilot is evaluated by measuring the pilot's workload which is defined alternately by medical, engineering, behavioral and life scientists in a variety of ways. All concerned are seeking to discover objective, measurable quantities of workload that relate to the safety and operability of new systems, but the specific measures of workload that are emphasized by different groups vary widely. Early in the design cycle, when proposals for new, workload reducing features are given preliminary evaluation, detailed measures of operator behavior, such as eye-movements, control stick activity, and time to respond are paramount. Later, when a new cockpit configuration has been selected for a more operational assessment, the measurements taken often involve the pilot's subjective evaluation, such as a rating scale of merit or a stated comparison with a familiar, base-line cockpit. The final method used by FAA certification authorities is the combination of pilot evaluation of his own performance and assessment by observer pilots of that same performance.

All such methods of testing workload are modeled on the engineering approach that regards the pilot as a control system, one subject to multiple in-flight stresses, and one that will be found to perform within normal limits or that will be found to be overloaded in some situations. But the pilot is not a mechanical device. As Kraft showed "Some pilots may improve their performance under heavier workloads, some may be unaffected, and some will deteriorate in their performance." (See reference 38). In consequence of this, it has been found that

none of the specific measures of workload gives reliable results of general validity when the question, how workload affects safety is asked. There is a limit, of course, a point at which any pilot can be overwhelmed. But that point is easy to identify in tests. As Westbrook et al put the matter, "It is well known that in some aircraft and in some flight conditions or emergencies, the pilot must work to the limit of his ability. Up to this limit it is also well known that if he desires he can maintain his performance of a task even though complaining bitterly...." (See reference 70).

In the absence of a proven method of measuring total pilot workload and relating the obtained measurements to safety, the proof of any theory or any design can only be achieved in flight, and then only proven by competent pilots flying the aircraft and observing other pilots flying the aircraft (see reference 56).

The Task Force review of workload measurement technology has revealed a complex field in which there is only partial agreement among authorities and only a partial understanding of the relations of workload to pilot performance. There is no immediate solution to the problem of defining an optimum workload, although design and test methods have been greatly improved.

Based on this evaluation of the complex field of workload measurement technology, the Task Force has found that those manufacturers who build transport category aircraft are conversant with the current technology and those manufacturers utilize the best current objective and subjective methods in the design and workload evaluation of cockpits. Further, the FAA certification authorities make an independent review of the workload documentation programs and then conduct a substantial body of proof flying before certificating as airworthy any transport category aircraft and its specified flight-crew complement.

It is not the province of the Task Force to offer a judgment as to how many pilots should comprise the flight-crew complement of any given airline aircraft. It is incumbent upon the Task Force, however, to state a judgment on the allegations that two crew member aircarrier aircraft are not operated as safely as three crew member aircraft. Our judgement is, simply, that the full accident record does not support the claim that three crew member aircraft have a better record. The total record actually favors the class of two crew member aircarrier aircraft, but this may be explained by a variety of factors unrelated to crew size.

It will be important in the future to insure that there is a better understanding of the airworthiness certification process

on the part of all interested parties. To this end, the Task Force has made the recommendation that a summary of uniform guidelines successfully employed by the Regions be published.

Reference Number	Author and Title	Page in Text	Remarks
1	ICAO Bulletin, "Accident Rates in Civil Aviation," July, 1975.	33	ICAO Member Accident Statistics shows fatality rate decreasing with time.
2	O'Donnell, J.J., "ALPA Proposal for FAA System Workload Study," Attachment letter to FAA. 3 March 1977.	1 2 14 26	Discusses evolution of third crew member. Notes lack of scientific approach in past. Outlines proposed system workload study.
3	"United Airlines, Inc. and the Air Line Pilots Association in the service of United Air Lines, Inc," 31 March 1970. Arbitration Award.	4	B-737 crew complement shall be 3 for UAL. UAL and ALPA submitted an exhaustive study; conclusions of each differed. The third man adds to safety. FAA near-midair study weighed heavily. Board did not want to insert new crew members but did not elect to change present size crew.
4	"Air Line Pilots Association and Aloha Airlines, Inc.," 23 November 1971. Arbitration Opinion and Award.	4	Determination is based on Aloha conditions and standards of operation. Good weather conditions. Four-head radio com-nav system is an aid. Little airport congestion. All crews previously flew BAC 1-11 with two. Crew size should be reduced to 2 and protective conditions agree upon.
5	"Wien Consolidated Airlines, Inc. and Air Line Pilots Association," Arbitration Opinion, 8 May 1973.	4	Wien should continue with three man crew. Canadian Airlines use 2 men. There are strong arguments for each side. Comparison with UAL and Aloha is critical particularly weather and

Reference Number	Author and Title	Page in Text	Remarks
			traffic congestion. Wien conditions are more like UAL.
6	Air Line Pilots Association, Proceedings of the Symposium on Man-System Interface: Advances in Workload Study, July 31 - August 1, 1978, ALPA, Washington, D. C.	16 17	Transcript of 10 technical papers plus 4 addresses are published. Captain O'Donnel's concluding remarks point to the possible long lead time in bringing this research to practical application. The intensity of research should be increased. "The results of this long-term research will not be on line until well into the 21st century."
7	Anderson, Coe M., "Civil Aircraft Accident Analysis in the U. S. 'The Jet Age'", AGARD-CP-212, June, 1976.	33	Lists 62 U.S. Air Carrier turbo-jet fatals 1959-1975, with breakdown by types. Discusses investigative methods Show declining accident rate with time. Reviews key accident series B-707 training accidents DC-8 longitudinal trim stability. Upsets in turbulence. Wind-shear approach accidents.
8	Boyd, Alan S., Chairman, CAB, letter to George S. Moore, Flight Standards Service, FAA, 19 October 1964.	2	In basic agreement with the then proposed alternation of Part 40.263 provided the inflight demonstration of workload and crew capability including test simulating one member becoming incapacitated, be required during the establishment of minimum crew complement under Part 46.720.

Reference Number	Author and Title	Page in Text	Remarks
9	Briggs, G.E., et al, "Multitask Time-Sharing Requirements," AMRL-TR-71-105, August, 1972.	22	Demonstrate the time-sharing effect.
10	Brown, E.L., G. Stone, and W.E. Pearce, "Improving Cockpits through Flight Crew Workload Measurement," Douglas Aircraft Co., Douglas Paper 6355, April, 1975.	21 24	Have developed capability to measure objectively flight crew workload. Can differentiate between alternative work stations, controls, and displays. Computerized technique gives quick and low-cost iteration. Primary measure is ratio of required time to time available, supplemented by hand-movement data.
11	Bruning, Gerhard F. "Simulation, and Introduction and Survey," in AGARD-CP-79-70.	20	Pilot performance measures are insensitive to increased workload up to the limit of pilot capacity. Quotes Westbrook on pilot workload. Workload effects are not fully understood today.
12	Butterfield, A.P., letter to ALPA, 24 October 1974.	vi	Decided against Adversary Hearings in aircraft certification.
13	Chiles, W. Dean, "Objective Methods for Developing Indices of Pilot Workload," FAA Report No. AM-77-15, July, 1977.	15	Broad survey article, 93 refs. or citations. Conclusion: lab, anal. and synthetic methods or simulators may be appropriate depending on nature of questions No exact "cook-book" guidelines are possible.

Reference Number	Author and Title	Page in Text	Remarks
14	Donchin, Emanuel, "Brain Electrical Activity as an Index of Mental Workload in Man-Machine Systems," Paper read at ALPA Symposium "Advances in Workload Study," Washington, D. C., 31 July - 1 Aug, 1978.	17	E.E.G. is very diffuse. Not sensitive to data processing. Although good for sleep/awake or dead/alive - no good for task. ERP is a signal extracted through signal averaging. Developing a tool for future research.
15	Eddy, Paul, Elaine Potter, and Bruce Page, Destination Disaster, From the Tri-motor to the DC-10: The Risk of Flying. Quadrangle, The New York Times Book Co., New York, 1976.	34	DC-6 accidents in 1948 led CAB to require third man. History of problems up to DC-10 door. Summarized statistics on safety of flying.
16	Ekstrom, Phyllis J., "Analysis of Pilot Workload in Flight Control Systems with different Degrees of Automation," Minneapolis-Honeywell Paper, May, 1962.	22	An analysis was made of pilot workload with an adaptive control system. Theoretical pilot workload was then verfied in a simulator using secondary task methods.
17	Federal Aviation Regulations -- Part 25, Airworthiness Standards. Amendment 25-3.	3	
18	Federal Aviation Regulations -- Part 121, Certification and Operations. Amendment 121-4.	3	
19	Federal Aviation Regulations - Part 25-3, 121-4 (Discussion of comments on notice of proposed rule making - Notice 64-21) Certified Document filed in "Certified Federal Register Documents - Part 25" folder, 30 FR 6066, April 29, 1965.	viii 2	Summary of comments on the amendment from Teamsters, FEIA, CAB, ATA, ALPA, and others plus conclusions by the FAA. Appendix D is added to FAR 25. 1523.

Reference Number	Author and Title	Page in Text	Remarks
20	Federal Register, Monday, February 27, 1978 Part II. DOT/FAA Notice No. 78-3, "Flight and Duty Time Limitations and Rest Requirements for Crew Members.	19	
21	Federal Aviation Regulations -- Part 25, Airworthiness Standards. FAR 25.771 (c) for controls. FAR 25.1303 (a), (b) and (c) and FAR 25.1321 (a) for displays.	7	
22	Gartner, Walter B. and Miles R. Murphy, "Pilot Workload and Fatigue: A Critical Survey of Concepts and Assessment Techniques." NASA-TN-D-8365, November, 1976.	12	Comprehensive survey with 158 references. Conceptual analysis of workload and fatigue. Critique of assessment methods. Refinements in assessment are suggested
23	Gerathewohl, Siegfried J., "Definition and Measurement of Perceptual and Mental Workload in Air crews and Operators of Air Force Weapons Systems" AGARD-CP-181, North Atlantic Treaty Organization, April, 1976.	12	Defines pilot workload after Gartner (input load, operator effort, work results). Discusses psychological and physiological methods of measurement plus measures in the operational environment.
24	Gerathewohl, Siegfried J., "Optimization of Crew Effectiveness in Future Cockpit Design: Biomedical Implications," <u>Aviation, Space, and Environmental Medicine</u>, November, 1976, 1182-1187.	8	Discusses changes to an electronic cockpit (digital A/C control and display system). Problems associated with selection, training and care of the flier. With automation, the pilot is psychologically in a dilemma since he is responsible but has little control input. He must be alert, but can he take over if necessary? Problems

Reference Number	Author and Title	Page in Text	Remarks
			of motivation and morale with automation (pilot loses gratification).
25	Gerathewohl, Siegfried J. et al, "Inflight Measurement of Pilot Workload: A Panel Discussion." Aviation, Space, and Environmental Medicine, June 1978, 810-822.	16	The sequence of technical meetings leading up to the 1978 meetings is outlined.
26	Gerber, R. C., "Crew Attitudes and Performance," Air Line Pilot, September, 1978, 19-21,51.	30	Discusses the impact of technology on the pilot. Today's aircraft are superbly engineered, and improvements in ATC, airports, etc. have produced the steadily improving safety record. When communications break down, airport facilities are poor, or equipment fails, the pilot is in the hot spot.
27	Glines, C. V., "A Statesmanlike Challenge," Air Line Pilot, October 1978, 6-13.	16	ALPA recently gathered experts in definition and measurement of cockpit workload and found that scientific research promises to have practical applications for aircraft design and operations.
28	Goerres, H.P., "Subjective Stress Assessment: A New, Simple Method to Determine Pilot Workload," Aviation, Space, and Environmental Medicine, June, 1977, 558-564.	15	Showed that evaluation of workload by subjective interview with pilots was a valuable method used in conjunction with assessment of task difficulty by experts, physiological recording, and secondary task measures.

Reference Number	Author and Title	Page in Text	Remarks
29	Gopher, Daniel, "Human Performance and Residual Capacity," Paper read at ALPA Symposium, "Advances in Workload Study, 31 July - 1 Aug, 1978.	17	Cited need for load profiles for complex tasks.
30	Graham, D.K., "Transport Airplane Flight Deck Development, Survey and Analysis: Report and Recommendations," NASA CR-145121, January, 1977.	24	NASA analysis in conjunction with TCV. Found little research going on in cockpit development for civil transports. Terminal area maneuvering will become more complex in future (profile desc.) Need for integrated displays, HUD, CDTI.
31	Hanna, R., Engineering Department, American Airlines, Inc., personal communication to R.L. Sulzer.	25	Discussed history of ATA cockpit standization efforts.
32	Hillman, R.E., and J.W. Wilson, "Future Flight Deck Design,' in Proceedings of a Symposium on Designing from the Inside Out, 6 February 1975, Royal Aeronautical Society.	14	There is no reason that even larger A/C cannot operate safely with two-crew. A two-crew flight deck will be unbalanced and inefficient if operated by three. Need master warning system, system management CDU'S data storage devices, to permit low-workload fault diagnosis without manuals.
33	Howitt, J.S., "The Assessment of Pilot Workload," in Proceedings of the Symposium on Flight Deck Environment and Pilot Workload, 15 March, 1973, the Royal Aeronautical Society.	12 18	Definitions of pilot workload. Value of subjective measurements. Physiological measures have deficiencies, we don't know what is optimum, but may be useful in comparing arousal level

Reference Number	Author and Title	Page in Text	Remarks
			with one equipment versus another. Discusses duty-day limitations.
34	Howlett, D.P. and R.W. Howard, "Cost Effectiveness of Systems," in Proceedings of a Symposium on Designing from the Inside Out, 6 February, 1975, Royal Aeronautical Society.	8	Half of all civil accidents could have been avoided if the crew had been able to assess the information available. Digitally programmed CRT's with the presentation selected according to the phase of flight will enhance ability of crew. Computer assessment of failures and built-in test equipment will support two crew operations.
35	Hurst, Ronald (Ed.) Pilot Error, A Professional Study of Contributory Factors, Crosby Lockwood Staples: London, 1976.	20	Pilot error actually means the task was too difficult or the pilot too fatigued. Role of the false hypothesis in error. Expectancy, attention problems. Pilot behavior influenced by monotony, preoccupation with one task, degraded skill due to lack of practice, plus personal problems, neurosis and tension.
36	Civil Aeronautics Board, Bureau of Safety, "Jet Transport Cockpit Review," BOSP-8-5-1, October, 1964.	2	Review of accidents, 1959-1963. No difference was found between third pilot and flight engineer. Weight not the best basis for crew size. First 7 years jet operations give better basis for deciding crew assignments and reducing workload.

Reference Number	Author and Title	Page in Text	Remarks
37	Kelly, Charles R. and Michael J. Wargo, "Cross-Adaptive Operator Loading Tasks," Human Factors, 9 (5), 1967, 395-404.	22	Secondary loading tasks overcome the problem that performance levels often fail to show the level of effort expended by an operator. In cross-adaptive procedure, difficulty level of the secondary task is automatically adjusted to maintain a standard level of performance to the primary task. The secondary score then is an index of workload on the primary task.
38	Kraft, Conrad L. and Charles L. Elworth, "Flight Deck Work Load and Night Visual Approach Performance" in AGARD-CP-No. 56, December 1969.	43	In simulator experiments found a "complex interaction" among workload, pilots, and conditions.
39	Lager, Carl, Pilot Relibility, The Royal Institute of Technology, Stockholm, 1974.	34	Reliability of human components in tech. systems discussed as a function of workload, provocations, and individual differences. U. S. and Canada have 50% better safety record than ICAO average. Accident investigation seldom reveals key weaknesses in system. SAS pilots rank lack of attention high. No one workload measure is adequate. Workload and heart rate correlation =.2. Need more research.
40	Lauschner, Erwin A. (Ed.) "Measurement of Aircrew Performance: The Flight	12	Conference proceeding. This contains 9 papers including Howitt and

Reference Number	Author and Title	Page in Text	Remarks
	Deck Workload and its Relation to Pilot Performance," AGARD-CP-56, North Atlantic Treaty Organization, December 1969.		Kraft-Elworth. A good source of reference on physiological measures.
41	International Civil Aviation Organization, "Manual of Civil Aviation Medicine." First edition 1974, Addendum No. 2, 11 January 1976, DOC 8984-AN/895.	18	Workload may cause fatigue due to cockpit layout, hours of work, rest in off-duty time, problems and delays, weather, etc. Scheduling of flight crew is an important cause of fatigue, and better quality rest facilities are needed.
42	McKelvey, Robert K. and Guy S. Brown, "Analysis of Approach Lighting Configurations for Visual Transition Under Category II Operating Conditions," FAA Report No. RD-64-134, September 1964.	20	Building blocks approach sought to show demonstrated gain in pilot performance for each increment in visual guidance. Statistical tests failed to show real differences in pilot performance while pilot comments indicated real differences in guidance.
43	NASA, "Meeting of Tri-Service Aircrew Workload Coordinating Committee," First Meeting Minutes: Donald A. Topmiller, AMRL/HEB, Wright-Patterson AFB, July, 1977. Second Meeting Minutes: Richard S. Dunn, DAVDL-AS, Ames Research Center, February, 1977.	24	Specialists in workload measurement for military and NASA conducted workshops. Better avionics can reduce workload but have costs. Air Force method is to use mock-ups, simulation, secondary task scores, and questionnaire methods. Problem is that workload measurement is most developed in biomechanical tasks while mental requirements on crew are more important.

Reference Number	Author and Title	Page in Text	Remarks
44	Miller, C.O., "Pilot Error by Design," Air Line Pilot, October, 1976, 15-18.	13	General reference for background information. Presents pilot capability and workload model that argues that accidents result from excess task loading. Makes no mention of accidents resulting from failure to follow rules and procedures.
45	Mohler, Stanley R., Memorandum to the Record, "Sub-Group 8, Meeting in Soviet Union, 21 August - 9 September, 1976"	18 22	Comprehensive survey of USSR aviation medicine. Special efforts are made to assure pilots rest in special hotels. Pilots are examined before entering duty. Secondary task methods measure workload.
46	NTSB, Accident Reports, File No's: 1-004, 7-19-70, UAL B-737, Philadelphia. 1-0048, 12-8-72, UAL B-737, Chicago. 1-0012, 3-27-68, Ozark DC-9, St. Louis.	14 42	
47	NTSB, Accident Report, File No. 1-0020, 9-11-74, EAL DC-9, Charlotte, Report No. NTSB-AAR-75-9.	12	
48	O'Donnell, J.J., Letter to the FAA, 1 August 1974.	42	States that there is a serious safety problem with DC-9 compared to three-man crew B-727.
49	O'Donnell, J.J., Letter to the FAA, 26 September 1974.	vi	Requested full disclosure of considerations bearing upon the safety aspect of the crew complement problem.

Reference Number	Author and Title	Page in Text	Remarks
50	O'Donnell, J.J., Letter to the FAA, 3 March 1977.	1 33	ALPA proposes that the FAA conduct a workload study looking forward to the future certification of new aircraft.
51	O'Donnell, J.J., "Human Factors and Aircraft Certification," Air Line Pilot, June, 1977, 14-16.	29	Human factors need more attention in airworthiness certification. FAA is too close to the manufacturers. Pilots become overloaded and then make mistakes. Today's 20 and 30 year old certification standards are a hazard to air safety.
52	O'Donnell, J. J., "Aircraft Certification: Changes Must be Made," Air Line Pilot, November 1978, 6-10.	vi	Cites numerous examples of failures in airworthiness certification and recommends opening the process to additional inputs. Discusses accidents and the need to tighten up various standards.
53	Naval Air Test Center, "Operator Workload: An Annotated Bibliography," Report No. SY-257R-76, 30 December, 1976.	12 15 22	Abstracts 83 key references, covering definitions, systems analysis, subjective techniques, psychomotor performance, information processing, physiological measures, and combined methods.
54	Parks, Donald L., "Current Workload Methods and Emerging Challenges," NATO Symposium on Mental Workload, Mati, Greece, 30 August - 6 September 1977.	12 14	Discusses the system-development process including activity analysis, man-machine interface tradeoffs, practical workload measurement, etc. Summarizes how crew-station design is conducted today (1977) including use of

Reference Number	Author and Title	Page in Text	Remarks
			computer programs, timeline analysis, etc. "Zero workload is not good news." Must keep the pilot in the loop to assure on-going cognizance of systems status and ability to monitor, manage and control.
55	Parks, Donald L., et al, "Mental Workload in Systems Applications," NATO Symposium on Mental Workload, Mati, Greece, 30 August - 6 September 1977.	21	"Many physiological measures have been tried, but no measure or group of measures has produced sufficiently useful results to be accepted as a standard and valid technique for measuring mental workload." Advantages and limitations of other ways of measuring mental workload are summarized. Need to know under what conditions man is a mental single-channel processor and when he has parallel processing capabilities.
56	Pew, Richard W., Statement by the Human Factors Society before the Defense Subcommittees of the Senate and House Appropriations Committees, Bulletin of the Human Factors Society, Sept. 1978, 4-5.	16 29 44	Total crew workload can not be measured reliably with present methods before hardware is actually built. Guess and test are today's methods.
57	Ramsden, J.M., The Safe Airline, MacDonald and James, London, 1976.	33 39	Summarizes safety statistics, showing the great improvement for each aircraft type as more experience with it was gained.

Reference Number	Author and Title	Page in Text	Remarks
			Fifth million hour accident rates were a fraction of the first. Shows safest countries with U.S. well above the average.
58	Reising, J.M., "The Definition and Measurement of Pilot Workload," AFFDL-TA-72-4-FGR, Flight Dynamics Laboratory, Wright-Patterson AF Base, U.S. Air Force, February, 1972.	12	Discusses relation of workload to piloting and alternative physiological and psychological measures.
59	Rolfe, J. and S.J. Lindsay, "Biological Measures of Workload," in Proceedings of the Symposium on Flight Deck Environment and Pilot Workload, 15 March 1973, the Royal Aeronautical Society.	15 18 19	Energy consumed shows the pilot to be in very light physical work. Subjective feelings reference workload are affected by various outside factors, unproductive delays and personal problems. Discusses method of measuring workload: observers, questionnaire, measured loading tasks, and physiological. Has 35 references.
60	Ruby, Charles H., Letter to FAA, 26 June 1964.	3 13	ALPA does not agree that crew complement can be properly determined during certification flight tests. Problems with instruments, anti-ice systems, WX, ATC, etc. cannot be simulated to represent actual airline operations.
61	Simpson, Robert W. and Thomas B. Sheridan, "Operator Workload	16	Much work has been done, but it is still not certain that we can

Reference Number	Author and Title	Page in Text	Remarks
	Measurement," Proposal to the FAA, Flight Transportation Laboratory, MIT, April, 1978.		create valid measures of pilot workload. Proposes a research program using both pilot test experiments and mathematical modeling.
62	Smith, C. W., "The Measures of Air Transport Risk," Flight International, 17 April 1975, 650-651.	33	Summarizes alternative safety indices, and shows the large improvements in safety that have come in the jet era. Passenger taking 10 trips a year would expect to be on board when a fatality occurs once in 38,000 years.
63	Air Line Pilots Association, "Some Workload and Environmental Characteristics of an Air Carrier Short Haul Turbo-Jet Operation," report on the B-737 study conducted with UAL in 1968.	4	ALPA summary of the results from the UAL study of two-pilot operation in B-737. Pilot workload is an elusive term. We do not have adequate objective measurement of the pilot tasks.
64	Special Air Safety Advisory Group (SASAG), Report to FAA, Report No. FAA-AFS-1-76-1, 30 July 1975.	20	An accident may occur because the pilot elects to continue an approach when in fact conditions should have dictated a missed approach. Carriers should provide training in crew coordination and command problem solving. Where there is a third crew member, he should be given specific duties.
65	Stoll, Hartwell G., "Flight Deck Design Techniques--A New Approach to Safety," AGARD-CP-212, North Atlantic Treaty Organization, June, 1976.	7	Digital computer technology may be applied to simplify pilot tasks (engine control for energy management, improved warning

Reference Number	Author and Title	Page in Text	Remarks
			systems, electronic displays, engineers panel reduction, etc.)
66	Air Line Pilots Association, "Summary of Results Report." 7 November 1968, B-737 Crew Complement Evaluation.	4	Summary of UAL/ALPA B-737 Crew Complement Evaluation.
67	United Airlines, "The Automatic Complacency," SAS paper reprinted in The Cockpit, April, 1978, Flight Operations Newletter.	12	Gives examples from real life showing that the pilot can become lax in attention to primary flight instruments when using an automatic control system. Pilot must stay in loop, use the machine, but be eternally vigilant, highly suspicious, and ready to reject a machine output that does not cross check.
68	Air Line Pilots Association, "The Need for a Three Man Crew on Jet Transports," July, 1967.	13	Report prepared by ALPA for the FAA, presents many instances that show the need for the third man in the B-737.
69	Wansbeek, G.C., "Alert for Safety--An Airline Approach," AGARD-CP-212, June, 1976, North Atlantic Treaty Organization.	19	Pilot error usually starts with violating a rule, intentionally or unintentionally. Summarizes world accident statistics. Describes KLM approach to teaching safety. The pilot must be alert and avoid self-confidence. The well trained crew has few problems, leading to a new danger-satisfaction, confidence, and a lowering of alertness.

Reference Number	Author and Title	Page in Text	Remarks
70	Westbrook, C.B., et al, "Handling Qualities and and Pilot Work Load," AGARD-CP-17, Stability and Control, Part 2 - Edited Version.	44	Quantitative measures of workload are needed. Various methods are coming into use. But at present simulation is best. There is a problem of using flight performance as an index of workload since the pilot can keep up his level of performance by working harder.
71	Wiener, Earl L., "Controlled Flight into Terrain Accidents: System-Induced Errors," Human Factors, April, 1977, 171-181.	12	Problem areas include pilot-controller communication, flight deck workload, noise-abatement procedures, government regulations, illusions, and warning systems. While most accidents trace to crew cockpit problems, pilot underload is a great threat to vigilance. The burning question is not how much work a man can do but how little he can do and remain safe.
72	Wilkinson, John and Hugh Field, "1976 Public Transport Accidents," Flight International 22 January 1977, pp. 177-181.	33	Shows the decline in accident rates from 1955 through 1976, tabulates all 1976 transport aircraft accidents of note, and discusses particular classes of accidents.
73	White, R.T., "Task Analysis Methods: Review and Development of Techniques for Analyzing Mental Workload in Multiple-Task Situations," Douglas Aircraft Co., Report No. MDC J5291, September, 1971.	12	Attempts to quantify workload reviewed. Cognitive and mental workload is stressed. Presents guidelines for an improved concept of workload. 97 References.

Reference Number	Author and Title	Page in Text	Remarks
74	Yates, Andy D. Jr., "Cockpit Discipline." Air Line Pilot, February 1977, 10-12.	19	Cockpit discipline and good habits are important. CVR shows that many pilots do not follow the standard operating procedures that they were taught. Overconfidence, refusal to recognize any errors (personality traits) are bad.

APPENDIX I

1977/1978 TASK FORCE ON COCKPIT WORKLOAD

ACCIDENT DATA

OPERATIONAL REVIEW - GROUND RULES

Five aircraft were selected as representative of the operational environment in the question of crew workload. These aircraft are:

1. British Aircraft Company (BAC) 1-11
2. Boeing 727
3. Douglas DC-8
4. Douglas DC-9
5. Boeing 737

The BAC 1-11 was selected as the longest running example, in years, of a two-man crew aircraft that has operated during all of the same years as the other four (4) aircraft examined. The Boeing 727 was selected because it was the "bench mark" aircraft utilized in the development and design of the Boeing 737. The Douglas DC-8 was selected because it was the "bench mark" aircraft utilized in the development and design of the Douglas DC-9. The Douglas DC-9 and the Boeing 737 were selected since it is the operation of these two aircraft, i.e., crew size, workload, etc., that is in question.

After reviewing both U.S. and non U.S. sources for exposure data, it was decided that only data which was under the direct control of an agency of the U.S. Government would be used for reduction and analysis. An overall review of worldwide data was completed to provide an impression of the relative size of the U.S. data compared to non-U.S. data. This review provided a high level of confidence that the majority of both the world's aircraft and their departures have been considered. U.S. data was extracted directly from the CAB publication entitled, "Airport Activity Statistic of Certificated Route Air carriers," and from data furnished by the management of Air California and Southwest Airlines. The data used to determine the 1976 U.S. Non-U.S. Market Share was extracted directly from ICAO Document, "Digest of Statistics No. 224 Fleet-Personnel Series FP-1976."

In those cases where an aircarrier changed from a three-man to a two-man crew during a particular year, no attempt was made to divide the departure data. The entire years departure data was allocated to the three-man crew. Of course each accident was allocated to the crew size involved. In the case where "advantage of leverage" was given through the rounding of numbers or other distribution of yearly data, it was always given to the three-man crew. The operational experience

selected for review is that of total (all services) departures as reported by the CAB and the two intra-state operators. Consideration was given to flight hours as a medium for exposure. However, the long enroute hours of the DC-8, and to a lesser measure the B-727, tended to mask the rate of exposure to the arrival and departure areas where the more serious accidents appear to occur more frequently. With the use of departures as a base, enroute/ arrival-departure differences were, to a lesser degree, still present. To correct this, the accidents most related to enroute operation where large geographical distances are covered were removed from rate consideration by the process called "normalizing" and listed for future readers to examine and discuss; i.e., turbulence, cases where there was obviously no direct or indirect action of the flight-deck crew related to the occurrence, such as a bird strike, passenger tripping on wet air-stair doors, or push-back backing over a ground crewman, and damage incurred from ground vehicles while aircraft was parked at gate. The task force has concluded that this normalization process places the accident incidence of each aircraft over a more common denominator. It is important that the reader note and recognize the dominance of both the U.S. manufacturers' and operators' experience in the aircarrier operations shown in the following tables of this appendix.

Aircarrier Fixed-Wing Turbo-Jet Aircraft Total
U.S. Vs Non-U.S. Aircraft Manufacturers and Operators
Worldwide Market Share by Millions of Departures
1976

U.S. Manufacturers	U.S. Carriers	Non U.S. Carriers	Total
Boeing	2,466,602	919,065	3,385,667
707	280,978	198,180	479,158
720	29,222	40,066	69,288
727	1,676,576	498,278	2,174,854
737	380,045	100,042	480,087
747	99,781	82,499	182,280
Douglas	1,501,973	1,156,024	2,657,997
DC-8	180,056	198,514	378,570
DC-9	1,173,911	826,749	2,000,660
DC-10	148,006	130,761	278,767
Convair	-	8,559	8,559
880	-	-	-
990	-	8,559	8,559
Lockheed	99,556	19,745	119,301
1011	99,556	19,745	119,301
Total	4,108,506	2,062,706	6,171,212
Non-U. S. Manufacturers			
Dassault	-	20,339	20,339
Mercure	-	20,339	20,339
20 Myst.	-	-	-
Airbus		-	12,301
12,301			

Non-U.S. Manufacturers	U.S. Carriers	Non U.S. Carriers	Total
300	-	12,301	12,301
Fokker	-	98,593	98,593
F-28	-	98,593	98,593
Hawker	-	78,453	78,453
HS-106	-	9,796	9,796
HS-121	-	68,223	68,223
HS-125	-	434	434
Ilyushin	-	6,618	6,618
IL-62	-	6,618	6,618
SUD -		118,301	118,301
SE-210	-	118,301	118,301
Tupolev	-	26,763	26,763
TU-134	-	26,763	26,763
BAC	110,835	168,133	278,968
1-11	110,835	153,597	264,432
VC-10	-	14,536	14,536
VFW -	-	-	
614	-	-	-
Yakovlev	-	12,219	12,219
YAK 40	-	12,219	12,219

U.S. Manufacturers	U.S. Carriers		Non U.S. Carriers		Total
Boeing	2.500	73%	.919	27%	3.419
Douglas	1.502	56%	1.156	44%	2.658
Convair	-	-	.008	100%	.008
Lockheed	.099	83%	.020	17%	.119
Total	4.101	66%	2.103	34%	6.204
Non-U. S. Manufacturers					
BAC	.111	40%	.168	60%	.279
Dassault	-		.020	100%	.020
Airbus	-		.012	100%	.012
Fokker	-		.098	100%	.098
Hawker	-		.078	100%	.078
Ilyushin	-		.006	100%	.006
SUD	-		.118	100%	.118
Tupolev	-		.027	100%	.027
VFW			-	-	-
Yakovlev	-		.012	100%	.012
Total	.111	17%	.539	83%	.650

Total U.S. Manufacturers Market Share
6.204 + .650 = 6.854, 6.204/6.854 — 90%

Total U.S. Aircarrier Market Share
4.101 + .111 = 4.212, 2.103 + .539 = 2.642 — 61%
4.212/6.854

DISCUSSION OF DATA
Boeing Aircraft

The Boeing 727 was used as the "bench mark" for the development of the Boeing 737. In all three calculations, i.e., total accident rate, normalized rate, fatal rate, the experience of the 737 showed a lesser or improved rate than did the comparison three-crew aircraft, the B-727.

What statistical conclusion is warranted in this B-727 versus B-737 comparison regarding size of flight deck crew? While it is true that in all three calculations the two-man crew operation reveals a lesser or improved rate, the size distribution and other properties of the raw "numbers" preclude making any positive statement other than that there is no significant difference in the level of safety between two and three-man operations.

While it is true that the only fatal 737 accident occurred with a three-man crew flying, the reviewer is cautioned to consider the fact that the largest share of exposure, approximately 80 percent of departures have been with three-man crews flying. Furthermore, at the time of that fatal accident and other B-737 three-man crew accidents, it is highly questionable that the third man had been given meaningful flight duties or that the design of the flight deck called for him to make any important contribution to safety.

Six certificated route carriers and two intra-state carriers comprise the U.S. population of aircarriers examined utilizing B-737 aircraft. Nine of the ten total B-737 accidents occurred while four of the six certificated route carriers were operating with three-man crews. These accidents included the only fatal B-737 accident. One accident, an overshoot type, occurred to one of these same four carriers after changing from three to two-man crews. Two of the six route carriers experienced no accidents either in three or two-man crew operations. The two intra-state carriers have had no accidents and have only operated with two-man crews. While it is true, in the opinion of the Task Force, that the two most serious B-737 accidents, i.e., 7/19/70, Philadelphia and 12/8/72, Chicago Midway, occurred with three-man crews flying, the striking factor in this record is that the B-737 has an excellent safety record. Taking that total record apart into two-man and three-man portions does not lead to a firm conclusion that there is any significant difference in the level of safety between two and three-man crews; certainly not one that would require a universal shift from two-man to three-man operations.

DOUGLAS AIRCRAFT

The Douglas DC-8 was used as the bench mark for the development of the Douglas DC-9. In all three calculations; i.e. total accident rate, normalized rate, fatal rate, the experience of the DC-9 showed a lesser or improved accident rate.

Regarding the size of the flight deck crew, six extremely serious accidents (all mid-air collisions) have occurred during the operation of the DC-9. Because of the heavy loss of life, these accidents must be considered critical in nature and should be examined regardless of the obviously improved overall rate compared to the predecessor aircraft. Each is reviewed below:

1-0002 3/9/67 Douglas DC-9

Collision with aircraft - both in flight. DC-9 was provided traffic information, target at 12:30, 1 mile. This warning was acknowledged 14 seconds before the collision. The cockpit voice recorder indicates that the DC-9 crew never detected the traffic that had been reported to them even though that traffic is thought to have been displayed in the clear glass areas of the windshields before the traffic advisory was issued. The DC-9 crew was in a better position to see-and-avoid than was the other aircraft. Approximately 5 seconds should have been sufficient to detect the target and initiate a change in direction of the DC-9. After detection, the aircraft response time would have been approximately 3 seconds. There is no evidence of any such attempted action by either crew.[1] The flight recorder readout indicates that the DC-9 was operating at a speed of 323 knots at the time of the collision within approximately 25 nautical miles from the point of intended landing.[2]

Size of flight deck crew - no factor.

1/NTSB aircraft accident report Mar. 9, 1967 N. Urbana, Ohio, p. 40

2/NTSB aircraft accident report Mar. 9, 1967 N. Urbana, Ohio, p. 33

1-0012 3/27/68 Douglas DC-9

Collision with aircraft - both in flight. Two fully rated and current DC-9 Captains and one First Officer were the flight deck crew. Hence, there were three potential flight deck lookouts on the DC-9. The tower issued a traffic advisory to the DC-9 regarding the other aircraft approximately 41 seconds before the accident. Ozark pilots, if exercising reasonable vigilance, could have been expected to sight the CESSNA in time to avoid the collision. On the other hand, the CESSNA crew could not have been expected to see and avoid the DC-9.[1/] Based on a fixed eye reference point, only the First Officer of the DC-9 had a protracted length of time during which the other aircraft would have been visible in the last minute before collision.[2/] The third crew member had two short 6 second intervals, approximately 12 seconds apart, when he could have but apparently did not see the other aircraft.[3/]

Size of flight deck crew - no factor.

1/NTSB aircraft accident report Mar. 27, 1968 St. Louis p. 18

2/NTSB aircraft accident report Mar. 27, 1968 St. Louis p. 15

3/NTSB aircraft accident report Mar. 27, 1968 St. Louis p. 11

1-0052 2/6/69 Douglas DC-9[1]

The accident occurred just before midnight. The weather was VFR. The small aircraft was operating in a closed left hand pattern. The Douglas DC-9 was making a long straight-in VFR approach. No tower was available. The initial IFR clearance, which was subsequently cancelled by the pilot, was issued from Brownsville, Texas. Unicom frequencies were not used by either aircraft to advise each other of their locations.

REILS were operating at the approach end of the active runway. The DC-9 crew were asked, by ground personnel to evaluate the lights - potentially a distraction.

The small aircraft was below the DC-9 horizon and probably was buried in the lights of the town of Harlingen.

DC-9 crew first saw a shadow of an aircraft pass over them and then felt a thud from the midair collision. They estimated that the collision occurred approximately one mile from the runway. The small aircraft was carried to the airport and dropped on the runway. The pilot, the sole occupant, was seriously injured.

It is questionable that the DC-9 crew could have seen the small aircraft. However, the pilot of the small aircraft should have seen the DC-9.

[1] This summary is based upon an interview conducted between the Task Force and NTSB Accident Investigator-in-charge. A Formal Accident Report Document was not prepared by NTSB, although a line item Discussion is contained on page 101 of NTSB Annual Review of Aircraft and Accident Data "U. S. Aircarrier operations, calendar year 1969, report number NTSB-ARC-71-1.

1-0016 9/9/69 Douglas DC-9

Collision with aircraft - both in flight. Deficiencies in ATC collision avoidance system were cited by NTSB as causual. The DC-9 was descending at approximately 2460 feet per minute and at an indicated airspeed of from 236 to 253 knots out of a cloud base 4000' to 2500'. Accordingly, the DC-9 crew would be unable to initiate a scan for unknown traffic, until 14 seconds before the collision point. The same applies to the other pilot.[1] The NTSB concluded, based on several cited studies, that 15 seconds is the absolute minimum time for detection, evaluation, and evasive action if a collision of this sort is to be avoided. On this basis, neither the DC-9 crew nor the other pilot would have had sufficient time after breaking out from the clouds to see and avoid the other aircraft even if they had devoted virtually their entire attention outside the cockpit, scanning for other aircraft.[2]

Size of flight deck crew - no factor.

1/NTSB aircraft accident report Sept. 9, 1969 - N. Fairland, Ind. P. 10

2/NTSB aircraft accident report Sept. 9, 1969 - N. Fairland, Ind. P. 11

1-0005 6/6/71 Douglas DC-9

Collision with aircraft - both in flight. Three independent radar systems failed to detect the primary target of the intruder aircraft; that military aircraft did not have an operating transponder and had not asked for radar advisory service.1/ No traffic advisory concerning the military aircraft was given the DC-9. At least 40 seconds prior to impact the military aircraft was less than 45° to the left of the DC-9 Captain's and First Officer's normal line.2/ In this case, the likelihood of a pilot either not seeing an intruder at all or seeing the intruder and misinterpreting visual cluses and then attempting an evasive maneuver based upon incomplete visual cues is highly possible.3/ The two crews had only marginal capability to detect, assess and avoid collision.4/

Size of flight deck crew-no factor.

1/NTSB accident report 6/6/71 N. Durante, California p.2

2/NTSB accident report 6/6/71 N. Durante, California p. 19

3/NTSB accident report 6/6/71 N. Durante, California p. 24

4/NTSB accident report 6/6/71 N. Durante, California p. 27

1-0021 12/4/71 Douglas DC-9

Collision with aircraft-both in flight. Traffic control personnel inadequacy of ATC facilities and services in terminal area. DC-9 descended onto CESSNA. The relative flight paths of two aircraft and the configurations physically limited each flight crew's ability to see and avoid the other aircraft.1/ The investigation disclosed that the CESSNA was not visible to the flight crew of the DC-9 during the period of time that the DC-9 was in visual meteorological conditions below the clouds since the CESSNA was below the DC-9's normal visual horizon.2/ The DC-9 remained behind and in the blind spot of the other aircraft until just before impact.3/

Size of flight deck crew-no factor.

1/NTSB aircraft accident report 12/4/71 Raleigh, N.C. p.1

2/NTSB aircraft accident report 12/4/71 Raleigh, N.C. p.5

3/NTSB aircraft accident report 12/4/71 Raleigh, N.C. p.5

In reviewing these six occurrences, the Task Force has found no reason to disagree with any of the NTSB findings. In two of these six occurrences, the potential traffic conflicts were conveyed to the aircarrier aircraft by ATC advisory in time to avoid collision. Evasive action was not, however, taken effectively. In one of these two occurrences, a two-man crew was involved; in the other it was a three-man crew. In the case of the two-man crew, the aircraft was exceeding the speed limit for its proximity to the destination airport. In two of the remaining four occurrences, the air traffic control system failed to identify the non-aircarrier aircraft. In both cases the Board questioned, because of the environment and geometry of circumstances, that the crews of either of the four aircraft would have had the time to see-and-avoid. In the two remaining midair collisions, both aircarrier aircraft were making straight-in approaches while the small aircraft were conforming to a VFR traffic pattern.

A common thread found throughout this review that binds all six of these accidents together is the NTSB comment on the mixing of controlled and non-controlled traffic in the terminal area. The terminal area is an extremely dynamic environment wherein the geometry of conflicting situations is always changing. In this environment each participant has to spend a very significant portion of his time continually reassessing his position relating to other controlled and non-controlled traffic.

The see-and-avoid concept of collision avoidance becomes less and less effective as traffic patterns become more complex, as relative speeds increase, as traffic densities increase, and as the mix of uncontrolled traffic increases. This concept has served, and will continue to serve the community well, subject to adequately constraining closing speeds and visibility requirements. In areas where high traffic densities and mixing IFR/VFR traffic occurs, it may become necessary to implement positive control to reduce the number of see-and-avoid encounters.

The Task Force has concluded that the FAA properly recognized each of these points and has taken effective corrective action in each case. A continual evolution of the regulatory environment has taken place to address problems associated with the increased traffic density, closing velocities, VFR/IFR traffic mix, and standardization of traffic pattern procedure. Beginning with 14 CFR Part 91-1 Docket Number 8367, and continuing through Docket Number 13543, Notice Number 74-6, the regulatory history and considerations indicate a concentrated effort to extend regulation to improve the safety of the see-and-avoid concept. The changes have been principally directed at extending the reaction time available to the pilots by increasing the visibility requirements for VFR, reducing closing velocities by speed restriction, and by providing advisory service to aid visual acquisition. In addition, in the areas where these

techniques collectively were insufficient, positive control of all traffic was instituted in the form of Terminal Control Areas for higher risk areas, which among other features imposed minimum pilot and aircraft equipment requirements.

In addition to the speed restrictions embodied in FAR 91.70, certain simultaneous communication improvements and procedural standardization for airports with and without operating towers were being evolved and have resulted in FAR 91.87 and 91.89. Aside from the standardization of landing patterns and procedures, the improvement in communications at non-tower airports is particularly significant in maintaining the highest safety level. Part 1 of the Airman Information Manual established the recommended traffic advisory practices for the non-tower airports for a variety of facility situations from FAA or Unicom equipped for air-to-air position broadcasts where no facilities exist.

We cannot place exact weight on these various changes, but it is notable that there have been no further mid-air collision catastrophies involving a DC-9 in over 7 years, although the number of DC-9 operations continue at a high rate. The last midair collision involving a Douglas DC-9 occurred December 4, 1971, over seven years ago.

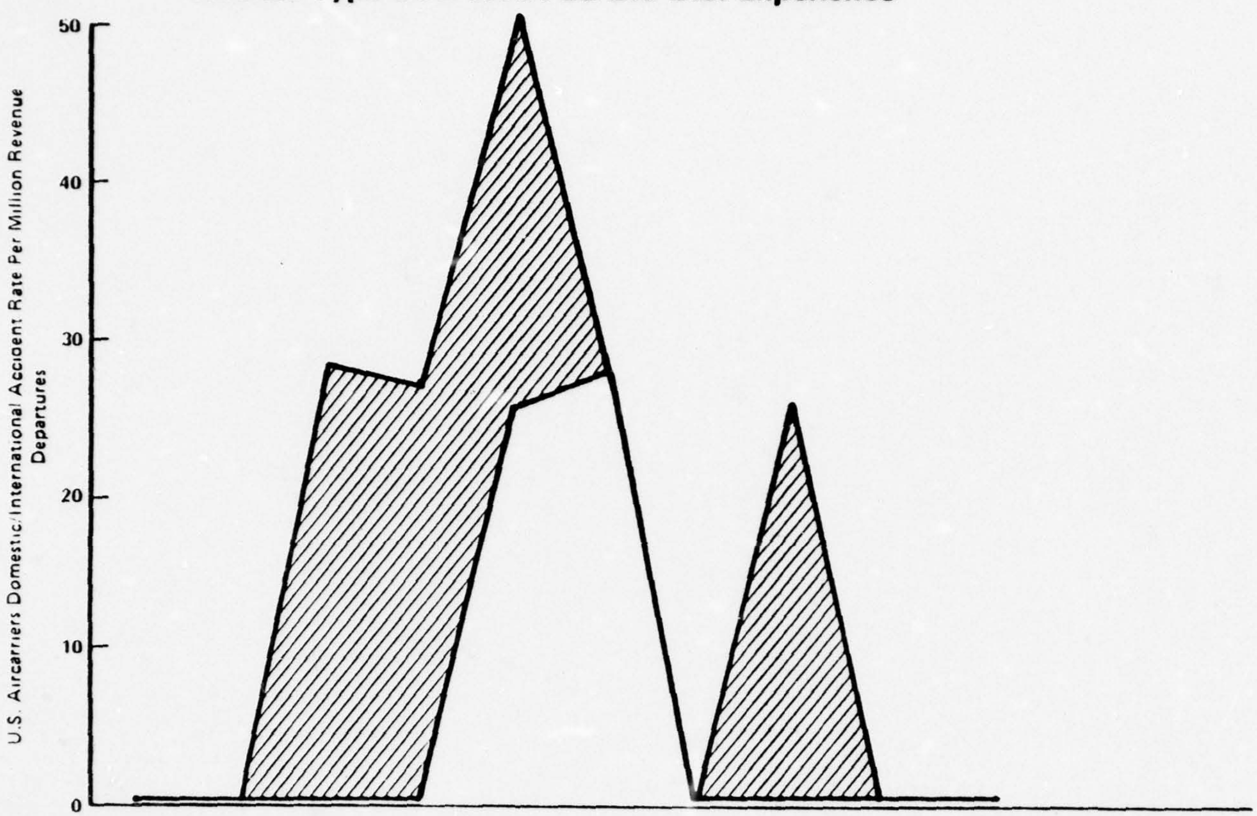
The Douglas DC-9 was operational well in advance of competing U.S. designs, therefore, it naturally "was the experience" that was gained in the operation of short-haul jet aircraft. Still today, only the Boeing 727 medium haul aircraft has more annual departures worldwide than the DC-9 but even that difference is small.

During the five years, 1972-1976, following the last DC-9 midair collision, the DC-9 total accident rate equaled 3.84, the normalized rate equaled 2.79 & Fatal Rate 0.70. Certainly there is no reason to expect a difference between the DC-9 and the B-737, but the pooled three member crew aircraft appear substantially better than the total and normalized rates for the B-727.

The BAC 1-11, still in active U.S. Certificated Route Aircarrier Service, represented the earliest U.S. two-man jet crew effort. Certainly its experience compares most favorably with the DC-9 and B-737. It far exceeds the level of safety of its French counterpart - the SUD AVIA SE-210 - in U.S. operation as a three-man crew aircraft.

TABLE 4.

Aircraft Type SUD AVIA SE 210 U.S. Experience



	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	Total
Total Accidents	0	0	1	1	2	1	0	1	0	0	6
Normalized Accident Total	0	0	0	0	1	1	0	0	0	0	2
Departures All Services	.020	.032	.036	.038	.040	.036	.039	0.39	.023	.013	.316
Total Accident Rate	0	0	27.78	26.31	50.0	27.78	0	25.64	0	0	18.99
Normalized Accident Rate	0	0	0	0	25.0	27.78	0	25.64	0	0	6.33
Fatal Accidents	0	0	0	1	0	0	0	0	0	0	1
Fatal Accident Rate	0	0	0	26.31	0	0	0	0	0	0	3.16

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB - Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

APPENDIX II

1977/1978 Task Force On Cockpit Workload

ACCIDENT DATA

U.S. AIR CARRIER ACCIDENTS

Examined for Period January 1, 1967 thru December 31, 1976:

The attached resumes were prepared based upon the Task Forces review of the National Transportation Safety Board's (NTSB) accident reports. These resumes utilize the following format.

1. NTSB file number
2. Date of occurrence
3. Aircraft make and model
4. Probable cause(s) as determined by the NTSB. An operational review by the task force, regarding human factors, crew work load, & flight deck crew size as it relates to each specific occurrence.

The accidents selected for this review are those involving five (5) specific aircraft makes and models.

1. Boeing 727
2. Boeing 737
3. Douglas DC-8
4. Douglas DC-9
5. BAC 1-11

To be included in the tabulation, these aircraft must have been operated by those operators defined as U.S. Certificated Route Carriers by the Civil Aeronautics Board (CAB). The departure data for the Certificated Route Carriers was extracted directly from the CAB publication Airport Activity Statistics of Certificated Route Air Carriers.

The departure data for both intra-state aircarriers, Air California and Southwest Airlines, that do not report to the CAB, was obtained directly from the management of each of the two airlines.

1-0002; 3/9/67; Douglas DC-9

Collision with aircraft--both in flight. DC-9 provided traffic information at 12:30 1 mile. This warning was acknowledged 14 seconds before the collision. The cockpit voice recorder indicates that the DC-9 crew never detected the traffic reported to them even though it was displayed in the clear glass areas of the windshields before the traffic advisory was issued. The DC-9 crew was in a better position to see-and-avoid the other aircraft. Approximately 5 seconds should have been sufficient to detect the target and initiate a change in direction of the DC-9. The aircraft response time would have been approximately 3 seconds. There is no evidence of any attempted action by either crew.1/ The flight recorder readout indicates that the DC-9 was operating at a speed of 323 knots at the time of the collision within approximately 25 nautical miles from the point of intended landing.2/

Size of flight deck crew--no factor.

1/ NTSB aircraft accident report Mar. 9, 1967, N. Urbana, Ohio, p. 40

2/ NTSB aircraft accident report Mar. 9, 1967, N. Urbana, Ohio, p. 33

1-0012; 3/27/68; Douglas DC-9

Collision with aircraft--both in flight. Two fully rated and current DC-9 Captains and one First Officer were the flight deck crew. The tower issued a traffic advisory to the DC-9 regarding the other aircraft approximately 41 seconds before the accident. Ozark pilots, if exercising reasonable vigilance, could have sighted the CESSNA in time to avoid the collision. The CESSNA crew could not have been expected to see and avoid the DC-9[1/]. Based on a fixed eye reference point, only the First Officer had a protracted length of time during which the other aircraft would have been visible in the last minute before collision.[2/] The third crew member had two short 6 sec. intervals approximately 12 sec. apart where he could have but did not see the other aircraft.[3/]

Size of flight deck crew--no factor.

1/ NTSB aircraft accident report, Mar. 27, 1968; St. Louis, Mo., p. 18

2/ NTSB aircraft accident report, Mar. 27, 1968; St. Louis, Mo., p. 15

3/ NTSB aircraft accident report, Mar. 27, 1968; St. Louis, Mo., p. 11

1-0039; 12/17/68; Douglas DC-9

Stall during initial climb. Pilot-in-command--inadequate preflight preparation and/or planning. Failed to follow approved procedures, directives, etc. T/O was made with known airframe icing.

Size of flight deck crew--no factor.

1-0016; 9/9/69; Douglas DC-9

Collision with aircraft--both in flight. Deficiencies in ATC collision avoidance system were cited by the NTSB as causal. The DC-9 was descending at approx. 2460 feet per minute and at an indicated airspeed of from 236 to 253 knots out of a cloud base 4000 to 2500' assigned. Accordingly, the DC-9 crew would be unable to initiate a scan for unknown traffic until 14 seconds before the collision point. Same applies to other pilot.1/ The NTSB concluded, that based on several cited studies that 15 seconds is the absolute minimum time for detection, evaluation, and evasive action if the collision is to be avoided. On this basis, neither the DC-9 crew nor the other pilot would have had sufficient time after breaking out from the clouds to see-and-avoid the other aircraft even if

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1/ NTSB aircraft accident report, Sep 9, 1969-N. Fairland, Ind. p.10

they had devoted virtually their entire attention outside the cockpit, scanning for other aircraft.1/

Size of flight deck crew--no factor

1-0021; 8/18/69; Douglas DC-9

Collided with object during taxi. Pilot-in-command misjudged distance. Right wing struck parked fuel truck.

Size of flight deck crew--no factor.

1-0027; 8/29/69; Douglas DC-9

Hard landing. Pilot-in-command inadequate supervision of flight. Dual student improper operation of flight controls. Unable to recover from high sink rate when trainee reduced power, lowered nose of aircraft during glide slope approach.

Size of flight deck crew--no factor.

1/ NTSB aircraft accident rpt, Sep 1969-N. Fairland, Ind., p-11

1-0046; 8/12/69; Douglas DC-9

Overshoot--collided with vehicle. Pilot-in-command--inadequate supervision of flight. Co-Pilot misjudged speed. Loss of effective braking due to dynamic hydroplaning, airport topography permitted excess water accumulation.

Size of flight deck crew--no factor.

1-0052; 2/6/69; Douglas DC-9 1/

The accident occurred just before midnight. The weather was VFR. The small aircraft was operating in a closed left hand pattern. The Douglas DC-9 was making a long straight-in VFR approach. No tower was available. The initial IFR clearance, which was subsequently cancelled by the pilot, was issued from Brownsville, Texas. Unicom frequencies were not used by either aircraft to advise each other of their locations.

REILS were operating at the approach end of the active runway. The DC-9 crew were asked, by ground personnel to evaluate the lights--certainly a distraction.

The small aircraft was below the DC-9 horizon and buried in the lights of the town of Harlingen.

DC-9 crew first saw a shadow of an aircraft pass over them and felt a thud of the midair collision. They estimated that the collision occurred approximately 1 mile from the runway.

The small aircraft was carried to the airport and dropped on the runway. The pilot, the sole occupant, was seriously injured.

It is questionable that the DC-9 crew could have seen the small aircraft. However, the pilot of the small aircraft should have seen the DC-9.

1/ This summary is based upon interview conducted between Task Force and NTSB Accident Investigator-in-charge. A formal accident report document was not prepared by NTSB, although a line item discussion is contained on page 101 of the "National Transportation Safety Board Annual Review of Aircraft Accident Data, U.S. Air Carrier Operations," Calendar Year 1969, Report Number NTSB-ARC-71-1.

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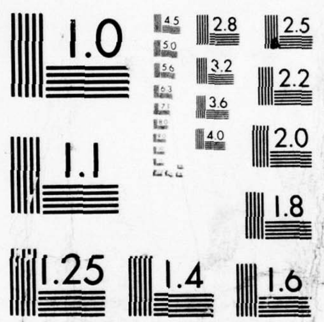

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1-0057; 4/24/69; Douglas DC-9

Turbulence in flight, clear air seat belt sign on. Passenger fractured knee while in lavatory.

Size of flight deck crew--no factor.

1-0002; 1/11/70; Douglas DC-9

Collided with trees on final approach. Pilot-in-command--improper IFR operation. Descended below MDA. Executed go-around. Crew did not receive latest weather. Company frequency unavailable.

Size of flight deck crew--no factor.

1-0016; 9/8/70; Douglas DC-9

Undershoot landing. Pilot's misjudgment of altitude due to sloping terrain absence of lights in approach area. Aircraft not positioned on glide slope.

Size of flight deck crew--no factor.

1-0023; 11/14/70; Douglas DC-9

Collided with trees on final approach. Descent below minimum descent altitude. Undetermined if descent due to improper cockpit instrumentation data use or altimeter system error.

Size of flight deck crew--no factor.

1-0003; 2/17/71; Douglas DC-9

Collided with wires/poles on final. Co-pilot--improper IFR operation. Pilot-in-command diverted attention from operation of aircraft. Inadequate monitoring of approach. Captain pre-occupied with pre-landing check. Co-pilot admitted establishing visual contact.

Size of flight deck crew--no factor.

1-0004; 1/11/71; Douglas DC-9

Pilot-in-command failed to maintain directional control weather considerably worse than forecast. Not aligned with runway about 1/8 mile from threshold aircraft. Right side of runway centerline, corrected left just before touchdown. Encountered drifting fog on runway.

Size of flight deck crew--no factor

1-0005; 6/6/71; Douglas DC-9

Collision with aircraft--both in flight. Three independent radar systems failed to detect the primary target of the other aircraft--that military aircraft did not have an operating transponder and had not asked for radar advisory service.1/ No traffic advisory concerning the military aircraft was given the DC-9. At least 40 seconds prior to impact the military aircraft was less than 45^{o} to the left of the DC-9 Captain's and First Officer's normal sight line.2/ In this case, the likelihood of a pilot either not seeing an intruder at all or seeing the intruder and misinterpreting visual clues is highly possible.3/ The two crews had only marginal capability to detect, assess and avoid collision.4/

Size of flight deck crew--no factor

1/ NTSB accident report 6/6/71, N. Durante, California, p.2

2/ NTSB accident report 6/6/71, N. Durante, California p.19

3/ NTSB accident report 6/6/71, N. Durante, California, p.24

4/ NTSB accident report 6/6/71, N. Durante, California, p.27

1-0021; 12/4/71; Douglas DC-9

Collision with aircraft--both in flight. Traffic control personnel, inadequacy of ATC facilities and services in terminal area. DC-9 descended on to CESSNA. The relative flight paths of the two aircraft and the configurations physically limited each flight crew's ability to see-and-avoid the other aircraft.1/ The investigation disclosed that the CESSNA was not visible to the flight crew of the DC-9 during the period of time that the DC-9 was in visual meteorological conditions below the clouds since the CESSNA was below the DC-9's normal visual horizon.2/ The DC-9 remained behind and in the blind spot of the other aircraft until just before impact.3/

Size of flight deck crew--no factor.

1/ NTSB aircraft accident report 12/4/71, Raleigh, NC, p.1

2/ NTSB aircraft accident report 12/4/71, Raleigh, NC, p.5

3/ NTSB aircraft accident report 12/4/71, Raleigh, NC, p.5

1-0022; 10/9/71; Douglas DC-9

Aircraft parked--engines not operating. Aircraft struck at rear of right wing tip area by ramp van. Ramp was adequately lighted. Aircraft lights were operating.

Size of flight deck crew--no factor.

1-0036; 8/18/71; Douglas DC-9

Bird collision. Black Vulture hit radome and penetrated pressure bulkhead.

Size of flight deck crew--no factor.

1-0038; 5/22/71; Douglas DC-9

Improper modification to isolate main cargo door hydraulic system from main hydraulic system. Door opened in flight.

Size of flight deck crew--no factor.

1-0002; 5/18/72; Douglas DC-9

Collision with ground controlled on level off/touchdown. Pilot-in-command failed to follow approved procedures, directives, etc. Improper in-flight decisions or planning and improper IFR operation. Flight did not report the outer marker in bound as requested by the tower controller and did not receive landing clearance. Weather below minimums.

Size of flight deck crew--no factor.

1-0003; 5/30/72; Douglas DC-9

Collision with ground uncontrolled vortex turbulence from preceding DC-10. Tower gave warning. Crew unable to evaluate due to insufficient information.

Size of flight deck crew--no factor.

1-0011; 3/19/72; Douglas DC-9

Engine malfunction on the ground during takeoff run. Second stage compressor disc number 2 engine failed. Separated at rear fan case. Engine parts damaged fuselage.

Size of flight deck crew--no factor.

1-0017; 12/20/72; Douglas DC-9

Collision with aircraft--one airborne. ATC system did not provide separation. Controller instructions ambiguous. Clarification not requested by CV-380 crew.

Size of flight deck crew--no factor.

1-0018; 5/10/72; Douglas DC-9

Fire or explosion on ground aircraft parked. Engines not operating--fire in left side aft cabin due to electrical short circuit in unused passenger service electrical receptical.

Size of flight deck crew--no factor.

1-0034; 6/14/72; Douglas DC-9

Hard landing. Pilot inadvertently manually deployed spoilers during level off.

Size of flight deck crew - no factor.

1-0035; 9/28/72; Douglas DC-9

Hard landing. Pilot-in-command improper level off and recovery from bounce landing. Broken fuselage frames and tail skid assembly.

Size of flight deck crew - no factor.

Z-011; 11/27/73; Douglas DC-9

Weather-low ceiling/thunderstorm. ILS approach-hit approach lights.

Size of flight deck crew - no factor.

Z-012; 11/27/73; Douglas DC-9

Overshoot. Weather and low clouds. Light rain showers and fog. Ran off end of runway into ravine.

Size of flight deck crew - no factor.

1-0004; 4/1/73; Douglas DC-9

Turbulence. Thunderstorms in area. Flight attendant fell. Use of seat belt sign undetermined.

Size of flight deck crew - no factor.

1-0011; 7/31/73; Douglas DC-9

Collided with object on final approach. Pilot-in-command improper IFR operation. Diverted attention from operation of aircraft. Unstable ILS approach, descended through decision height. Lowering ceiling and visibility. Sea fog, questionable flight director display. Non-standard ATC services. Hit sea wall.

Size of flight deck crew - no factor.

1-0031; 12/21/73; Douglas DC-9

Turbulence in-flight clear air. Seat belt sign off. No forecast of clear air turbulence, steward injured.

Size of flight deck crew - no factor.

1-0035; 12/17/73; Douglas DC-9

Engine failure. Pilot-in-command failed to follow approved procedures, directives, etc. Delayed action in aborting takeoff, 2 inches of snow reported on runway. On takeoff, encountered heavy slush, continued into heavier slush. Runway measurement revealed 3-5 inches snow and slush. Aircraft hit taxiway lip.

Size of flight deck crew - no factor

1-0003; 2/15/74; Douglas DC-9

Turbulence in flight clear air. Seat belt sign on. Seat belt off. Flight attendant in rear gallery thrown against ceiling, fell to floor.

Size of flight deck crew - no factor.

1-0010; 9/1/74; Douglas DC-9

Turbulence. Seat belt sign on. Seat belt off. P/A announcement made prior to turbulence encounter. Flight attendant injured trying to hold service cart down.

Size of flight deck crew - no factor.

1-0015; 2/21/74; Douglas DC-9

Turbulence in flight clear air. Pilot-in-command--improper in-flight decisions or planning - seat belt sign off. Clear air turbulence advisory from pilot reports ahead. Airspeed 340 knots. Stewardess fell in galley.

Size of flight deck crew - no factor.

1-0020; 9/11/74; Douglas DC-9

Collision with ground - controlled, on final approach. Co-pilot improper IFR operation. Pilot-in-command failed to follow approved procedures, directives, etc. Crew coordination poor. Lack of awareness during approach. Altitude call outs not made at FAF, 500 ft. above field or 100 ft. above minimum descent altitude.

1-0037; 11/21/74; Douglas DC-9

Collision with aircraft - both on ground. Taxiing for takeoff. DC-9 parked on taxiway K, other aircraft on outer taxiway. Alternate taxiway closed due to construction.

Size of flight deck crew - no factor.

1-0011; 6/23/76; Douglas DC-9

Collision with ground - uncontrolled. Under investigation.

Size of flight deck crew - no factor.

1-0020; 11/16/76; Douglas DC-9

Aborted takeoff. Collided with ditches. Under investigation.

Size of flight deck crew - no factor.

1-0022; 11/12/76; Douglas DC-9

Gear collapsed taxiing from landing, pilot-in-command failed to see and avoid objects or obstructions. Diverted attention from operation of aircraft. Stopped to let company aircraft by. During turn to ramp right gear entered construction area to the right and rear of the aircraft. Lights not too specific. ATC personnel - failure to advise of unsafe airport conditions.

Size of flight deck crew - no factor.

1-0027; 11/17/76; Douglas DC-9

Evasive maneuver to avoid collision. Other aircraft read back wrong altitude. ATC did not correct read back. Flight attendant injured.

Size of flight deck crew - no factor.

1-0003; 3/30/67; Douglas DC-8

Inadequate supervision of flight, improper operation of power plant, power plant controls, and flight controls by pilot-in-command and dual student simulated two-engine out.

Size of flight deck crew - no factor.

1-0016; 4/4/67; Douglas DC-8

Turbulence, associated with clouds and thunderstorms, seat belt sign on while PAX in lavatory - PAX fell broke leg returning to seat.

Size of flight deck crew - no factor.

1-0017; 5/1/67; Douglas DC-8

Stewardess wearing high heel shoes lost her balance and fell. Broke ankle. Very light turbulence.

Size of flight deck crew - no factor.

1-0030; 6/9/67; Douglas DC-8

Thunderstorm activity. Flight attendants injured while performing flight duties.

Size of flight deck crew - no factor.

1-0039; 8/30/67; Douglas DC-8

Pilot-in-command failed to follow approved procedures, directives, etc. Turbulence, associated with clouds, thunderstorms, pilot failed to divert around clouds on advice of ground radar. Selt belt sign off. PAX injured.

Size of flight deck crew - no factor.

1-0041; 10/1/67; Douglas DC-8

Turbulence in flight, clear and associated with clouds, thunderstorms. Seat belt sign on, PAX warned by crew. PAX failed to remain in seat.

Size of flight deck crew - no factor.

1-0049; 8/25/67; Douglas DC-8

Turbulence in-flight clear. Seat belt sign off. Weather slightly worse than forecast.

Size of flight deck crew - no factor

1-0052; 9/16/67; Douglas DC-8

Evasive maneuver to avoid collision with Navy T-33. DC-8 under radar control, T-33 was not. PAX injured back.

Size of flight deck crew - no factor

1-0022; 8/14/68; Douglas DC-8

Turbulence in flight, clear air. Seat belt sign off. PAX fell in aisle, fractured left foot.

Size of flight deck crew - no factor.

1-0048; 3/23/68; Douglas DC-8

Wheels-up landing, maintenance, servicing, inspection: inadequate maintenance and inspection.

Size of flight deck crew - no factor.

1-0053; 1/28/68; Douglas DC-8

Turbulence in flight, clear air PAX injured. Crew stated both announcement made and seat belt sign was on.

Size of flight deck crew - no factor.

1-0064; 4/23/68; Douglas DC-8

Overshoot.

Size of flight deck crew - no factor.

1-0066; 8/6/68; Douglas DC-8

Turbulence, associated with clouds, thunderstorms. Ground and aircraft radar did not show cell. Weather forecast inaccurate. PAX injured.

Size of flight deck crew - no factor.

1-0068; 1/25/68; Douglas DC-8

Turbulence associated with clouds, thunderstorms. Incorrect weather forecast. Seat belt sign on. PAX and flight attendant injured.

Size of flight deck crew - no factor.

1-0069; 6/12/68; Douglas DC-8

Turbulence associated with clouds and thunderstorms. Pilot-in-command failed to follow approved procedures, directives, etc. Seat belt sign on. Pilot did not give verbal warning to passengers and crew. PAX injured.

Size of flight deck crew - no factor

1-0012; 3/16/69; Douglas DC-8

Turbulence in flight, clear air. Seat belt sign was on. Stewardess thrown to ceiling while in aisle.

Size of flight deck crew - no factor.

1-0018; 4/27/69; Douglas DC-8

Turbulence. Associated with clouds, thunderstorms. Pilot-in-command failed to follow approved procedures, directives, etc. Seat belt sign on. Pilot gave crew and PAX ample warning, but did not slow aircraft to company max thunderstorm penetration speed. Six PAX injured.

Size of flight deck crew - no factor.

1-0019; 4/27/69; Douglas DC-8

Turbulence, associated with clouds, thunderstorm. Seat belt sign on. Radar inoperative. Pilot warned flight attendants, but they did not check PAX seat belts. Eight PAX were injured.

Size of flight deck crew - no factor.

1-0028; 1/31/69; Douglas DC-8

Gear collapsed on landing roll. Landing gear: Nose wheel assemblies, improperly installed. Incorrect factory installation. Nose gear upper cross tube end bearings assembled improperly. 125 total time on aircraft.

Size of flight deck crew - no factor.

1-0030; 7/22/69; Douglas DC-8

Turbulence, associated with clouds, thunderstorms. Pilot-in-command failed to follow approved procedures, directives, etc. Seat belt sign was turned on. Beverage service in progress.

Size of flight deck crew - no factor.

1-0031; 8/2/69; Douglas DC-8

Turbulence, associated with clouds, thunderstorms. Seat belt sign on. PAX injured while returning from Blue Room.

Size of flight deck crew - no factor.

1-0035; 5/8/69; Douglas DC-8

Collision with aircraft. Both on ground. Pilot-in-command failed to see and avoid other aircraft. ASDE not on. No traffic information issued by ground control.

Size of flight deck crew - no factor.

1-0038; 7/23/69; Douglas DC-8

Turbulence. In-flight clear air. Pilot-in-command failed to follow approved procedures, directives, etc. Seat belt sign turned on too late. Thunderstorm and cumulus build-ups in area.

Size of flight deck crew - no factor

1-0047; 8/2/69; Douglas DC-8

Turbulence associated with clouds, thunderstorms. Seat belt sign on. Pilot requested vector around storm. ATC radar was inoperative. Stewardess inadvertently released seat belt.

Size of flight deck crew - no factor.

1-0050; 11/20/69; Douglas DC-8

Collided with parked aircraft. Pilot-in-command misjudged clearance. Taxied/parked without proper assistance.

Size of flight deck crew - no factor.

1-0054; 11/28/69; Douglas DC-8

Failure of compressor disc, compressor rotor. 12th stage compressor disc, number 4 engine failed. Aborted safely.

Size of flight deck crew - no factor.

1-0056; 9/17/69; Douglas DC-8

Gear collapsed. Landing gear: main gear - shock absorbing assembly. Left gear lower lug of fwd bogie beam failed.

Size of flight deck crew - no factor.

1-0058; 10/16/69; Douglas DC-8

Collided with dirt bank on aborted takeoff. Gear collapsed. False ground spoiler position indicator. Takeoff warning horn malfunctioned.

Size of flight deck crew - no factor.

1-0004; 3/18/70; Douglas DC-8

Turbulence in flight, clear air. Seat belt sign off. PAX fell and broke ankle.

Size of flight deck crew - no factor.

1-0009; 5/29/70; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Pilot-in-command failed to follow approved procedures, directives, etc. Seat belt sign on. Aircraft was deviating south of course between two large build-ups. Warning to flight attendants was late. Flight attendant injured.

Size of flight deck crew - no factor.

1-0010; 7/27/70; Douglas DC-8

Aircraft destroyed. Descent due to inattention of crew to altitude while attempting to maintain visual contact. Weather conditions precluded such operation.

Size of flight deck crew - no factor.

1-0013; 4/20/70; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on. Pilot was steering around build-ups showing on aircraft radar. Crew gave adequate warning of turbulence.

Size of flight deck crew - no factor.

1-0022; 5/27/70; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. Two flight attendants and one PAX injured. Pilot-in-command failed to follow approved procedures, directives, etc. Flight in thunderstorm area. Aircraft radar inoperative. Pilot was receiving steers but didn't notify ATC that radar was inoperative.

Size of flight deck crew - no factor.

1-0029; 6/9/70; Douglas DC-8

Fire/explosion on ground. Fire in brakes, wheel assembly, wheel well. Number 7 escape chute rupture during evacuation. Two tires of right main landing gear blew. Aborted takeoff.

Size of flight deck crew - no factor.

1-0031; 8/15/70; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorm. Seat belt sign on; seat belt not fastened. Controller turned aircraft into thunderstorm. Pilot had requested deviation. Controller decision influenced by heavy sector workload. Two flight attendants injured.

Size of flight deck crew - no factor.

1-0034; 9/21/70; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on. One PAX and one flight attendant injured.

Size of flight deck crew - no factor.

1-0011; 5/15/71; Douglas DC-8

Aircraft parked. PAX evacuated aircraft by overwing exits; flaps were up. Ground power unit failed. Bomb threat previously. Five PAX injured.

Size of flight deck crew - no factor.

1-0012; 5/18/71; Douglas DC-8

Flight attendant did not hear call bell regarding impending takeoff; fell and broke arm.

Size of flight deck crew - no factor.

1-0028; 1/3/71; Douglas DC-8

Turbulence in flight, clear air forecast substantial correct. Seat belt sign off. Pilot-in-command failed to follow approved procedures, directives, etc. Encountered forecast clear air turbulence at FL370 100 mi. east of Kansas City, Mo. Captain had checked other flights and centers, no turbulence reported.

Size of flight deck crew - no factor.

1-0034; 7/26/71; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened. Weather radar did not show return. Flight above broken to overcast deck. One flight attendant injured.

Size of flight deck crew - no factor.

1-0043; 8/14/71; Douglas DC-8

Cargo shifted to rear. Aborted OK. Investigation under the jurisdiction of Gov't of Japan.

Size of flight deck crew - no factor.

1-0045; 12/23/71; Douglas DC-8

Turbulence in flight clear air. Seat belt off; seat belt sign off. Encountered turbulence with no warning or indication. Autopilot engaged. One flight attendant injured.

Size of flight deck crew - no factor.

1-0019; 2/26/72; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened. Seat belt sign on. One PAX inadvertently released seat belt and was thrown from seat. One PAX was hit by a flying object.

Size of flight deck crew - no factor.

1-0024; 3/3/72; Douglas DC-8

Fire or explosion on ground. Unnecessary and uncoordinated evacuation initiated by stewardess over-reacting to an engine torch on starting.

Size of flight deck crew - no factor.

1-0029; 4/21/72; Douglas DC-8

Collided with a man on the runway on takeoff.

Size of flight deck crew - no factor.

1-0042; 5/7/72; Douglas DC-8

Turbulence in flight clear air. Seat belt sign off. Unforecasted clear air turbulence.

Size of flight deck crew - no factor.

1-0002; 2/28/73; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened; seat belt sign on. One flight attendant injured.

Size of flight deck crew - no factor.

1-0027; 10/8/73; Douglas DC-8

Ground crewman run over by nose gear during push back from gate. Investigation under jurisdiction of Gov't of Japan.

Size of flight deck crew - no factor.

1-0021; 8/20/73; Douglas DC-8

Turbulence in flight clear air. Seat belt not fastened; seat belt sign on. One PAX injured.

Size of flight deck crew - no factor.

1-0022; 7/27/74; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened; seat belt sign on. Injuries to PAX and flight attendants not secured by seat belts. Flight attendant thrown from left aft flight attendant seat; seat belt opened.

Size of flight deck crew - no factor.

1-0034; 11/6/74; Douglas DC-8

Turbulence in flight, clear air. Seat belt sign off. As seat belt sign was turned off, elderly PAX left seat. Brief turbulence encountered. PAX fell and injured ankle.

Size of flight deck crew - no factor.

1-0043; 12/5/74; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened. Seat belt sign on. Crew gave both visual and oral warnings.

Size of flight deck crew - no factor

1-0004; 3/21/75; Douglas DC-8

Turbulence in flight, clear air. Seat belt not fastened; seat belt sign off. One flight attendant injured.

Size of flight deck crew - no factor.

1-0015; 8/8/75; Douglas DC-8

Turbulence in flight, clear air. Seat belt not fastened; seat belt sign off. No clear air turbulence. Encountered clear air turbulence and flight attendant was thrown from jump seat which folded. After encounter, flight attendant struck seat.

Size of flight deck crew - no factor.

1-0028; 9/22/75; Douglas DC-8

Turbulence. Encountered wake vortex from L-1011 which crossed VORTAC at approximately same altitude about 3 minutes prior.

Size of flight deck crew - no factor.

1-0038; 12/22/75; Douglas DC-8

Gear collapsed. Pilot unable to see taxiway due to ice/snow cover and inoperative taxiway lights. Aircraft taxied off hard surface.

Size of flight deck crew - no factor.

1-0041; 9/20/75; Douglas DC-8

Takeoff 22L JFK, used calculations for 22R. Struck ILS components on takeoff.

Size of flight deck crew - no factor.

1-0013; 5/27/76; Douglas DC-8

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. PAX disregarded flight attendant's warning to return to seat.

Size of flight deck crew - no factor.

1-0005; 7/19/67; Boeing 727

Collision with aircraft. Both in-flight. The other aircraft deviated from IFR clearance into flight path of this aircraft.

Size of flight deck crew - no factor.

1-0013; 3/6/67; Boeing 727

Turbulence in-flight, clear air. Seat belt not fastened; seat belt sign was on. One flight attendant was injured.

Size of flight deck crew - no factor.

1-0022; 4/7/67; Boeing 727

Wheels up landing. Main gear shock absorbing assembly jammed. Landed on foamed runway. Intentional wheels up landing. Gear jammed up due to bolt NAS 1105-13DW lost in flight. Flight engineer injured in evacuation.

Size of flight deck crew - no factor.

1-0026; 4/29/67; Boeing 727

Gear collapsed. Overload failure; 1/4-1/2 inch of slush on runway. Reverted rubber found on all main gear tires. Scrubbing on nose gear tires.

Size of flight deck crew - no factor.

1-0034; 5/15/67; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt not fastened. PAX out of seat when aircraft encountered turbulence. Seat belt sign on well before turbulence encounter.

Size of flight deck crew - no factor.

1-0057; 6/9/67; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened. Aircraft penetrated isolated thunderstorm cell. PAX were adequately warned. Request to divert delayed by departure control.

Size of flight deck crew - no factor.

1-0006; 3/2/68; Boeing 727

Evasive maneuver to avoid collision. On top of overcast, visibility unrestricted. Traffic advisory issued. Unidentified aircraft. First seen by crew at about one mile.

Size of flight deck crew - no factor.

1-0019; 6/26/68; Boeing 727

Precautionary landing at airport. False fire warning. PAX jumped from wing. Broken wire found shorted to a fire warning element connector.

Size of flight deck crew - no factor.

1-0021; 6/12/68; Boeing 727

Collision with aircraft; both in-flight. Pilot-in-command failed to see-and-avoid.

Size of flight deck crew - no factor.

1-0023; 3/21/68; Boeing 727

Delayed action in aborting takeoff; collided with ditches. Co-pilot misused or failed to use flaps. Co-pilot set flaps 2 degrees vice 5 degrees. Armed takeoff warning horn sounded. Pilot continued takeoff; aborted after lift-off.

Size of flight deck crew - no factor.

1-0025; 6/8/68; Boeing 727

Gear collapsed. Pilot-in-command misjudged speed. Normal landing accomplished. Pilot waited too late to slow aircraft for turn-off. Gear overload failure.

Size of flight deck crew - no factor.

1-0027; 7/11/68; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Unable to change ATC clearance. Penetrated cumulus line. Seat belt sign on. Crew and PAX warned. Two flight attendants injured.

Size of flight deck crew - no factor.

1-0029; 9/23/68; Boeing 727

Precautionary landing at airport. PAX injured when they jumped or slid from leading edge at wings. Possibility of dynamite aboard.

Size of flight deck crew - no factor.

1-0037; 8/7/68; Boeing 727

Undershoot - gear collapsed. Landed about 2300 ft. short of displaced threshold. Left gear beam attach fitting failed.

Size of flight deck crew - no factor.

1-0050; 4/2/68; Boeing 727

Turbulence in flight, clear air.

Size of flight deck crew - no factor.

1-0057; 6/3/68; Boeing 727

Collided with approach lights. Captain failed to arrest descent; struck approach light pier at LaGuardia. Executed missed approach. Further damage JFK airport.

Size of flight deck crew - no factor.

1-0067; 10/3/68; Boeing 727

Turbulence. One flight attendant injured.

Size of flight deck crew - no factor.

1-0070; 7/5/68; Boeing 727

Turbulence. One flight attendant injured.

Size of flight deck crew - no factor.

1-0004; 1/18/69; Boeing 727

Spatial disorientation. Departed with Number 3 generator inoperative. Fire warning Number 1 and engine shut down. Attitude instrument inoperative due to complete loss of electrical system.

Size of flight deck crew - no factor.

1-0006; 5/14/69; Boeing 727

Collision with aircraft; both on the ground. While waiting for clearance, one B-727 was struck by another that was taxiing to takeoff position.

Size of flight deck crew - no factor.

1-0007; 2/9/69; Boeing 727

Complete engine failure/flameout Number 1 engine. Investigation under jurisdiction of West Germany Gov't.

Size of flight deck crew - no factor.

1-0008; 1/14/69; Boeing 727

Driver backed ground power unit into side of aircraft.

Size of flight deck crew - no factor.

1-0014; 6/25/69; Boeing 727

Gear collapsed - swerve. Excessive speed produced hydrodynamic pressure between tires/runway. Pilot advised to expedite up runway.

Size of flight deck crew - no factor.

1-0015; 2/9/69; Boeing 727

Turbulence in flight, clear air. Seat belt sign on. PAX returning to seat fell and broke ankle.

Size of flight deck crew - no factor.

1-0022; 1/16/69; Boeing 727

Evasive maneuver to prevent collision with 1 of 3 Navy jet aircraft.

Size of flight deck crew - no factor.

1-0024; 9/26/69; Boeing 727

Collided with 9 year old mentally retarded child during night takeoff.

Size of flight deck crew - no factor.

1-0036; 9/15/69; Boeing 727

Escape chute ripped during evacuation. Stewardess inadvertently activated alarm.

Size of flight deck crew no factor.

1-0044; 7/29/69; Boeing 727

Gear collapsed. Pilot-in-command inadequate preflight preparation and/or planning. Attempted to takeoff from runway too short for aircraft. Signs did not properly identify runway. Runway markings incorrect.

Size of flight deck crew - no factor.

1-0055; 12/13/69; Boeing 727

Daughter of elderly PAX inadvertently seated her mother on retracted flight attendant jump seat. Mother fell.

Size of flight deck crew - no factor.

1-0008; 2/25/70; Boeing 727

Turbulence; seat belt sign on. Aircraft encountered light chop. PAX age 78 fell and broke hip while walking in buffet area.

Size of flight deck crew - no factor.

1-0015; 6/3/70; Boeing 727

Fire or explosion on ground, A.P.U. caught fire on ramp. Freon line from bottle was disconnected.

Size of flight deck crew - no factor.

1-0026; 12/28/70; Boeing 727

Hard landing. High bounce from poor approach touchdown. Improper recovery technique. Lack of cockpit crew coordination.

Size of flight deck crew - no factor.

1-0036; 5/18/70; Boeing 727

Fire or explosion on the ground. Flap selector leaked hydralic fluid on A.P.U. exhaust, smoke entered cabin through vents. Passenger injured during evacuation.

Size of flight deck crew - no factor.

1-0038; 11/20/70; Boeing 727

Turbulence in-flight, clear air. Seat belt not fastened; seat belt sign on. Flight attendant arose from seat, thrown against armrest, closet, floor; received two broken ribs.

Size of flight deck crew - no factor.

1-0040; 11/4/70; Boeing 727

Gear collapsed. Right main left gear aft trunnion support beam failed.

Size of flight deck crew - no factor.

1-0047; 12/16/70; Boeing 727

Gear collapsed. Left main landing gear trunnion beam failed at bearing hole; stress corrosion cracking.

Size of flight deck crew - no factor.

1-0009; 5/14/71; Boeing 727

Turbulence in-flight, clear air. Seat belt not fastened; seat belt sign on. Descended from FL310 to FL240 due to moderate chop. Crew and PAX warned. Hit clear air turbulence. Unforecast for time and area.

Size of flight deck crew - no factor.

1-0008; 9/4/71; Boeing 727

Pilot-in-command failed to follow approved procedures, directives, etc. Crew did not use all navigation aids or identify navigation aid. (Station).

Size of flight deck crew - no factor.

1-0010; 4/1/71; Boeing 727

Management supervisor of stewardess overreacted when A.P.U. torched. Caused unwanted evacuation. All stewardesses were unaware of proper procedure.

Size of flight deck crew - no factor.

1-0015; 7/19/71; Boeing 727

Gear collapsed. Pilot-in-command failed to follow approved procedures, directives, etc. Boost pump switches overheated. Crew mistook source of odor. Took wrong actions. Landed too fast for runway condition.

Size of flight deck crew - no factor.

1-0024; 12/29/71; Boeing 727

Turbulence in-flight, clear air. Seat belt sign on. Crew warned PAX of expected turbulence. Injured PAX was in blue room.

Size of flight deck crew - no factor.

1-0031; 2/26/71; Boeing 727

Gear collapsed on landing roll. Left gear trunnion support beam failed at attach hole.

Size of flight deck crew - no factor.

1-0033; 6/8/71; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. PAX left seat for blue room despite crew warning of possible turbulence. Crew received radar vectors due to thunderstorms.

Size of flight deck crew - no factor.

1-0037; 3/29/71; Boeing 727

Turbulence in-flight, clear air. Seat belt sign on. Turbulence not forecast. Stewardesses checking PAX seat belts, serving meal. Flight attendant injured.

Size of flight deck crew - no factor.

1-0046; 2/7/71; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Pilot-in-command failed to follow approved procedures, directives, etc. Pilot allowed cabin service in known area of possible turbulence per company policy.

Size of flight deck crew - no factor.

1-0047; 11/17/71; Boeing 727

Engine failure. 8th stage compressor disc number 2 engine failed for undetermined reason. Debris damaged vertical stabilizer and hydraulic systems.

Size of flight deck crew - no factor.

1-0008; 2/19/72; Boeing 727

Precautionary landing because of false fire warning. PAX injured during evacuation.

Size of flight deck crew - no factor.

1-0028; 6/28/72; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Flight encountered small cumulus cloud which did not show on weather radar. Seat belt light was on but no signal to flight attendants.

Size of flight deck crew - no factor.

1-0030; 1/10/72; Boeing 727

Turbulence in-flight, clear air. Seat belt sign on. Seat belt not fastened. Seat belt signs were on during entire trip. PAX was injured while returning from right aft lavatory.

Size of flight deck crew - no factor.

1-0031; 9/30/72; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Pilot-in-command failed to follow approved procedures, directives, etc. Flew in area of forecast thunderstorm activity.

Size of flight deck crew - no factor.

1-0040; 11/8/72; Boeing 727

Gear collapsed on takeoff. Main landing gear trunnion support beam failed due to stress corrosion cracking.

Size of flight deck crew - no factor.

1-0044; 10/1/72; Boeing 727

Gear collapsed. False fire warning. Precautionary landing. Stress corrosion, front trunnion bearing support fitting. Pre-existing cracks produced during rework.

Size of flight deck crew - no factor.

1-0046; 10/30/72; Boeing 727

Air frame failure on the ground taxiing. Left main gear trunnion support beam separated.

Size of flight deck crew - no factor.

1-0049; 6/10/72; Boeing 727

Fire or explosion on the ground. Portable oxygen bottle ignited due to hydro-carbon oil contamination when on for PAX use.

Size of flight deck crew - no factor.

1-0005; 3/3/73; Boeing 727

Pilot-in-command misjudged distance and speed. Unable to stop on remaining runway due to hydroplaning. Turned off runway into mud to taxiway. Gear collapsed.

Size of flight deck crew - no factor.

1-0007; 3/17/73; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Two flight attendants injured. Known thunderstorms in area, observed on radar. Encountered moderate to severe turbulence.

Size of flight deck crew - no factor.

1-0033; 12/9/73; Boeing 727

Collided with object on the ground. Pilot-in-command failed to see-and-avoid objects or obstructions. During turn back to taxiway pilot check wing clear of hangar. Stabilizer balance hit open door extending out about 15'.

Size of flight deck crew - no factor.

1-0036; 12/22/73; Boeing 727

Evacuation due to bomb threat. PAX injured jumping from leading edge of wing. Inadequate evacuation briefing by flight attendants.

Size of flight deck crew - no factor.

1-0039; 8/8/73; Boeing 727

Fire or explosion in flight. Number four wheel lockout--deboost valve damaged causing brake drag, overheated wheel, internal tire fire, and tire blow out.

Size of flight deck crew - no factor.

1-0002; 1/4/74; Boeing 727

Engine failure or malfunction on takeoff. Tire disintegrated; No. 3 engine ingested pieces of rubber. Aborted. PAX injured during evacuation using escape slides.

Size of flight deck - crew no factor.

1-0018; 4/1/74; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not secured. Elderly lady broke leg when thrown from seat during turbulence encounter.

Size of flight deck crew - no factor.

1-0028; 7/10/74; Boeing 727

Number three fire warning in climb. Returned to airport. Injuries on evacuation. No fire, false fire warning.

Size of flight deck crew - no factor.

1-0029; 12/1/74; Boeing 727

Collision with ground on final approach.

Size of flight deck crew - no factor.

1-0031; 12/1/74; Boeing 727

Airframe failure in-flight. Pilot-in-command failed to follow approved procedures, directives, etc. Pitot switch not on. Failed to recognize pitot icing. Lost control. Left horizontal stabilizer failed. Aircraft destroyed.

Size of flight deck crew - no factor.

1-0036; 12/1/74; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened; seat belt sign on. Flight attendant underestimated First Officer's warning, delayed in returning to seat. Thrown against ceiling.

Size of flight deck crew - no factor.

1-0038; 11/25/74; Boeing 727

Collided with parked aircraft. Aircraft being pushed back for engine start. Tail hit other aircraft parked at gate.

Size of flight deck crew - no factor.

1-0039; 9/21/74; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened; seat belt sign on. Cabin attendant left seat to initiate her duties. Fell and sustained broken ankle.

Size of flight crew deck - no factor.

1-0040; 11/17/74; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt not fastened; seat belt sign on. Two PAX injured. Encountered moderate to heavy turbulence during flight in vicinity of thunderstorm activity. Crew gave ample warning.

Size of flight deck crew - no factor.

1-0002; 2/14/75; Boeing 727

Fire or explosion on ground. Unsecured wire bundle chafed against hyd line, arced causing hole. Ignited fluid. Flight engineer preflight.

Size of cockpit crew - no factor.

1-0006; 6/24/75; Boeing 727

Collided with runway or approach lights. Traffic control personnel cleared aircraft to wrong runway for existing conditions. Severe weather hazard existed along approach path.

Size of cockpit crew - no factor.

1-0012; 8/7/75; Boeing 727

Collision with ground on takeoff. Probably encountered tailwind in excess of 60 knots at or near point of impact.

Size of cockpit crew - no factor.

1-0022; 11/12/75; Boeing 727

Collision with ground on final approach. Pilot-in-command -- improper IFR operation. Lost sight of runway environment during heavy rain below decision height, failed to execute approach. Hit 282 ft. short.

Size of cockpit crew - no factor.

1-0027; 8/23/75; Boeing 727

Gear collapsed on touchdown. Fatigue fracture left main landing gear link assembly trunnion.

Size of flight deck crew - no factor.

1-0029; 8/16/75; Boeing 727

Fire or explosion on ground. After prolonged taxi operation, fire developed in right wheel assembly.

Size of flight deck crew - no factor.

1-0047; 12/22/75; Boeing 727

Turbulence in flight, clear air. Seat belt sign off; seat belt off. Pilot-in-command failed to follow approved procedures, directives, etc. One PAX injured.

Size of flight deck crew - no factor.

1-0002; 1/17/76; Boeing 727

Cargo loader, driver undetermined, ran into lower fuselage. PAX injured using emergency exits. Aircraft parked at Jetway. Engines not operating.

Size of flight deck crew - no factor.

1-0003; 4/5/76; Boeing 727

Overshoot. Pilot-in-command failed to follow approved procedures, directives, etc. Misjudged distance and speed. Initiated go-around with insufficient runway remaining, then aborted. Abandoned ILS approach when island in sight.

Size of flight deck crew - no factor.

1-0004; 2/22/76; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. Flight attendant injured.

Size of flight deck crew - no factor.

1-0005; 4/27/76; Boeing 727

Overshoot. Pilot-in-command failed to follow approved procedures, directives, etc. Misjudged distance and speed. Operational supervisory personnel failed to provide adequate directives, manual, equipment. Used 30 degrees of flap instead of 40. Initiated go-around with insufficient runway remaining. Aborted. No information on aircraft go-around performance.

Size of flight deck crew - no factor.

1-0007; 3/3/76; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. One PAX injured.

Size of flight deck crew - no factor.

1-0008; 2/16/76; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. Crew made P.A. announcement of possible turbulence. PAX left seat.

Size of flight deck crew - no factor.

1-0012; 2/16/76; Boeing 727

Engine failure/malfunction on takeoff; aborted. 2nd stage blade retaining pin failed. Loose blade cut fuel inlet line. PAX injured due to torn evacuation slide.

Size of flight deck crew - no factor.

1-0017; 8/8/76; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. PAX left seat unobserved; fell returning from lavatory.

Size of flight deck crew - no factor.

1-0019; 6/12/76; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. Severe in-flight turbulence encountered at FL230 for 3 to 5 seconds. Two flight attendants injured.

Size of flight deck crew - no factor.

1-0021; 8/2/76; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on; seat belt fastened. Infant tossed into overhead and landed in aisle during turbulence, was seated with belt fastened.

Size of flight deck crew - no factor.

1-0026; 8/4/76; Boeing 727

Left main gear would not extend. Wheel-up landing. Uplock universal block left main landing gear separated from stress corrosion, cracking.

Size of flight deck crew - no factor.

1-0018; 8/10/68; Boeing 737

Passenger fell while returning to seat from the blue room.

Size of flight deck crew - no factor.

1-0012; 7/19/70; Boeing 737

Engine failure or malfunction. Pilot-in-command improper in-flight decisions or planning. Number 1 engine first stage turbine blade. Pilot terminated takeoff above V2, at approximately 50 feet of altitude - thought both engines failed.

Size of flight deck crew - no factor.

1-0030; 5/7/71; Boeing 737

Fire warning number 2 engine. Captain's evacuation order misinterpreted by cabin attendant as emergency. Some PAX jumped off wing.

Size of flight deck crew - no factor.

1-0048; 12/8/72; Boeing 737

Stall on final approach. Pilot-in-command inadequate supervision of flight. About 700 feet high at outer marker during localizer approach. Spoilers deployed to flight descent position from outer marker to minimum descent altitude level off.

Size of flight deck crew - no factor.

1-0016; 6/29/73; Boeing 737

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Seat belt not fastened. Flight attendant disregarded seat belt sign and P/A warning.

Size of flight deck crew - no factor.

1-0013; 7/24/73; Boeing 737

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Steered through thunderstorm activity using airborne radar. Flight attendant injured performing enroute duties.

Size of flight deck crew - no factor.

1-0025; 8/22/73; Boeing 737

Unwanted sudden yaw damper induced rudder input due to defective coil in system. Control malfunction during previous takeoff. Pilot-in-command failed to follow approved procedures, directives, etc.

Size of flight deck crew - no factor.

1-0019; 10/28/73; Boeing 737

Overshoot/gear collapsed. Pilot-in-command improper operation of flight controls. Landed long and fast at about 2600 feet beyond approach end of runway. Delayed with spoilers, not manually deployed, ran off end of runway.

Size of flight deck crew - no factor.

1-0022; 8/16/73; Boeing 737

Malfunction of flight control system. Defective coil in "B" system transfer valve. Flight attendant injured, same aircraft involved in File No. 10025, 8/22/73, accident.

Size of flight deck crew - no factor.

1-0001; 3/31/75; Boeing 737

Pilot-in-command misjudged distance, speed, and altitude and failed to initiate go-around. Co-pilot failed to follow approved procedures, directives, etc. Required call outs not provided P.I.C. Touched down about 2375 feet from departure end of 8681 foot runway.

Size of flight deck crew - no factor.

1-0004; 6/23/67; British BAC 1-11

Collision with ground - uncontrolled. Engine air, through malfunctioning non return, and open air delivery valves ignited fire in plenum chamber. Tail separated in flight.

Size of flight deck crew - no factor.

1-0031; 2/29/68; British BAC 1-11

Ground loop/swerve. Co-pilot - improper operation of brakes and/or flight controls. Pilot-in-command inadequate supervision of flight. Directional control not established before reversing. 3/4 inch of slush on runway. Wind variable 20k gusting to 32k.

Size of flight deck crew - no factor.

1-0019; 2/26/70; British BAC 1-11

Elderly PAX tripped on bottom step of air stair. Adequate warning and assistance was given. Aircraft parked - engines not running.

Size of flight deck crew - no factor.

1-0040; 8/15/73; British BAC 1-11

Turbulence in flight clear air. Seat belt sign on since departing from Boston. PAX seated, near window. Seat belt not fastened. Belts checked previously.

Size of flight deck crew - no factor.

1-0021; 7/24/74; British BAC 1-11

Deplaning passenger twisted ankle and fell on forward air stair. Aircraft parked. Engines not operating.

Size of flight deck crew - no factor.

1-0026; 9/20/74; British BAC 1-11

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Seat belt not fastened. Child thrown from seat, fell injuring shoulder in aisle.

Size of flight deck crew - no factor.

1-0033; 11/21/74; British BAC 1-11

While deplaning, elderly passenger slipped and fell from wet aircraft stair. Aircraft parked engines not operating.

Size of flight deck crew - no factor.

APPENDIX III

1977/1978 TASK FORCE ON CREW WORKLOAD

ACCIDENT DATA CHARTS

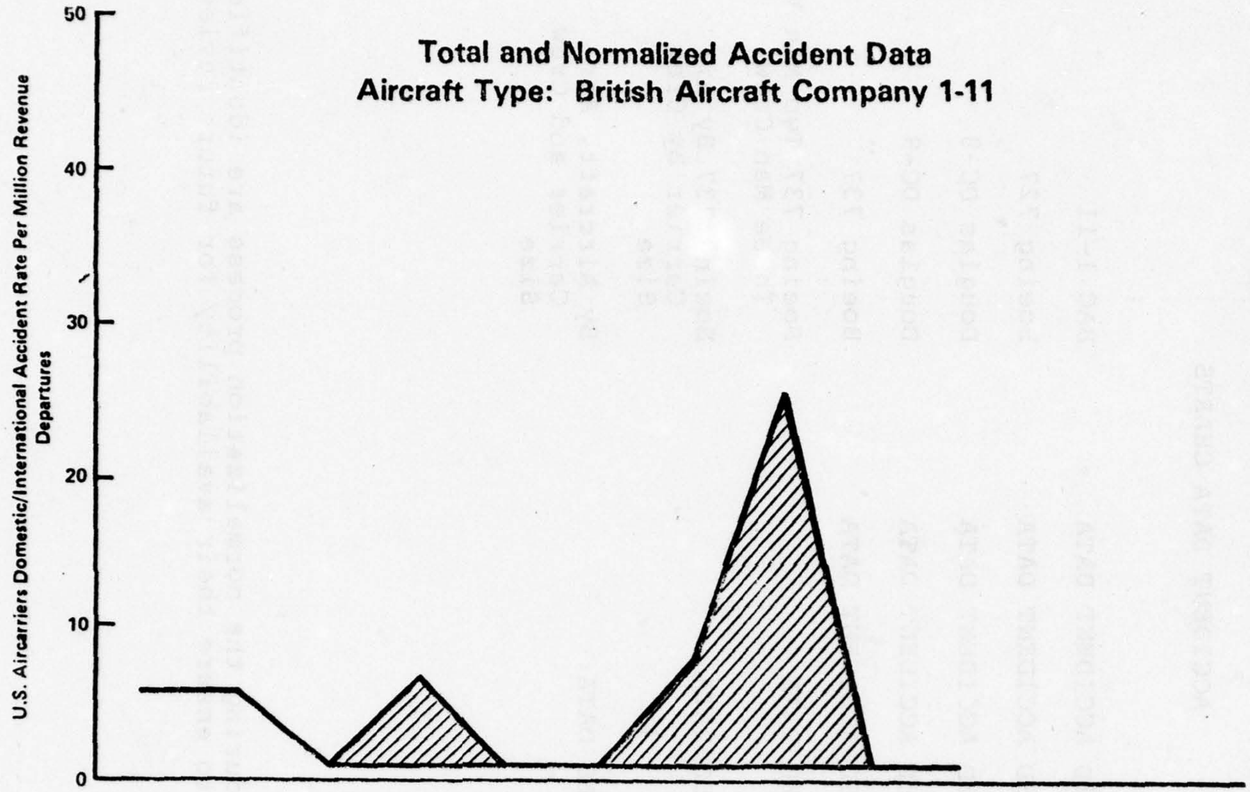
TOTAL AND NORMALIZED ACCIDENT DATA	BAC 1-11
TOTAL AND NORMALIZED ACCIDENT DATA	Boeing 727
TOTAL AND NORMALIZED ACCIDENT DATA	Douglas DC-8
TOTAL AND NORMALIZED ACCIDENT DATA	Douglas DC-9
TOTAL AND NORMALIZED ACCIDENT DATA	Boeing 737
TOTAL AND NORMALIZED DATA	Boeing 737 Two Man Vs. Three Man Crew
TOTAL AND NORMALIZED DATA	Boeing 737 By Air Carrier By Crew Size
TOTAL AND NORMALIZED DATA	By Aircraft, Air Carrier and Crew Size

NOTE:

Accidents removed during the normalization process are identified and listed herein to ensure their availability for future review and discussion.

TABLE 5.

Total and Normalized Accident Data
Aircraft Type: British Aircraft Company 1-11



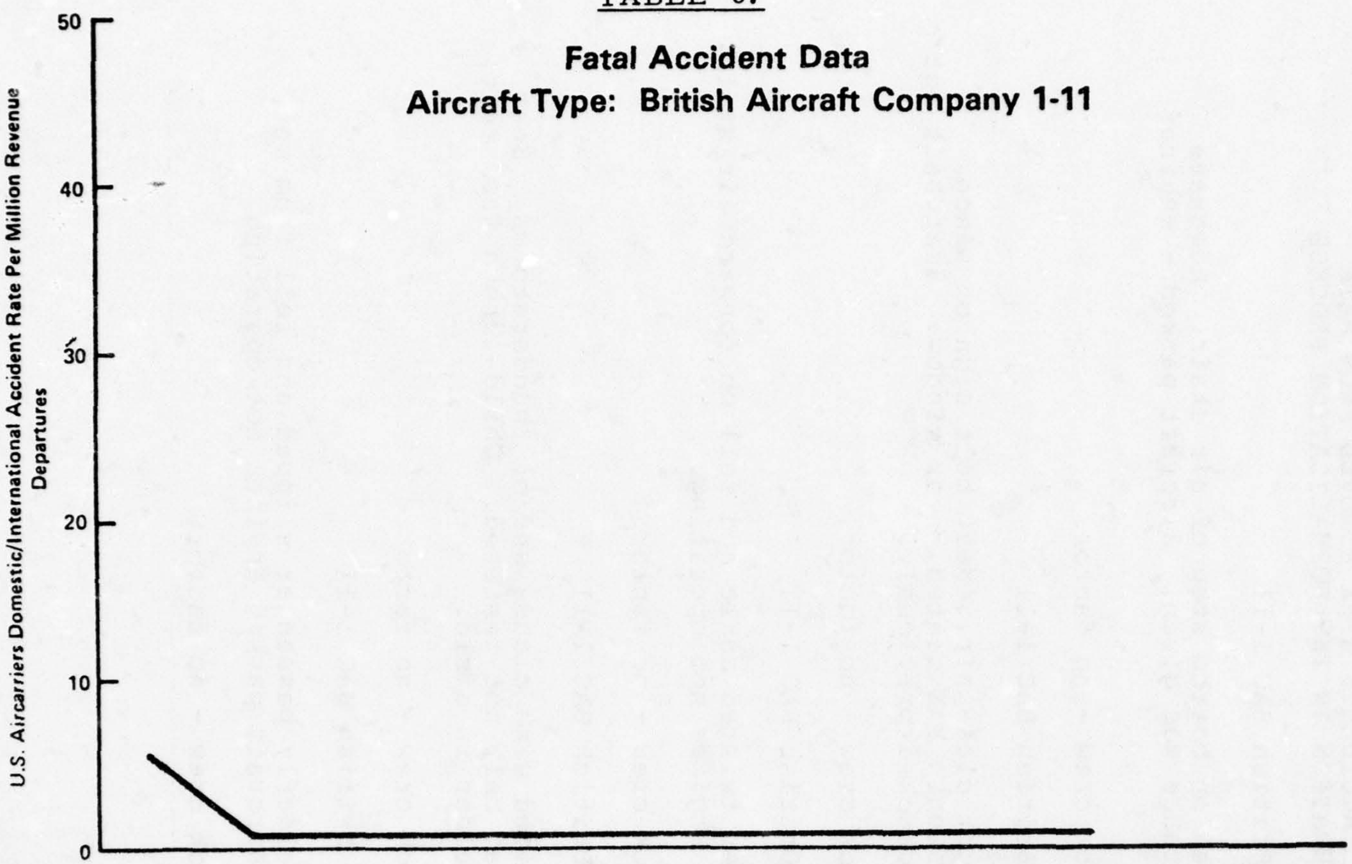
	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	1	1	0	1	0	0	1	3	0	0	7
Normalized Accident Total	1	1	0	0	0	0	0	0	0	0	2
Departures All Services	.185	.196	.203	.166	.130	.129	.128	.121	.114	.111	1.483
Total Accident Rate	5.40	5.10	0	6.02	0	0	7.81	24.79	0	0	4.72
Normalized Accident Rate	5.40	5.10	0	0	0	0	0	0	0	0	1.35
Fatal Accidents	1	0	0	0	0	0	0	0	0	0	1
Fatal Accident Rate	5.40	0	0	0	0	0	0	0	0	0	.67

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 6.

Fatal Accident Data

Aircraft Type: British Aircraft Company 1-11



	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	1	1	0	1	0	0	1	3	0	0	7
Normalized Accident Total	1	1	0	0	0	0	0	0	0	0	2
Departures All Services	.185	.196	.203	.166	.130	.129	.128	.121	.114	.111	1.483
Total Accident Rate	5.40	5.10	0	6.02	0	C	7.81	24.79	0	0	4.72
Normalized Accident Rate	5.40	5.10	0	0	0	0	0	0	0	0	1.35
Fatal Accidents	1	0	0	0	0	0	0	0	0	0	1
Fatal Accident Rate	5.40	0	0	0	0	0	0	0	0	0	.67

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

THESE ACCIDENTS WERE REMOVED FROM RATE CONSIDERATION IN THE NORMALIZATION PROCESS

1-0019; 2/26/70; British BAC 1-11

Elderly PAX tripped on bottom step of air stair. Adequate warning and assistance was given. Aircraft parked - engines not running.

Size of flight deck crew - no factor.

1-0040; 8/15/73; British BAC 1-11

Turbulence in flight clear air. Seat belt sign on since departing from Boston. PAX seated, near window. Seat belt not fastened. Belts checked previously.

Size of flight deck crew - no factor.

1-0021; 7/24/74; British BAC 1-11

Deplaning passenger twisted ankle and fell on forward air stair. Aircraft parked. Engines not operating.

Size of flight deck crew - no factor.

1-0026; 9/20/74; British BAC 1-11

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Seat belt not fastened. Child thrown from seat, fell injuring shoulder in aisle.

Size of flight deck crew - no factor.

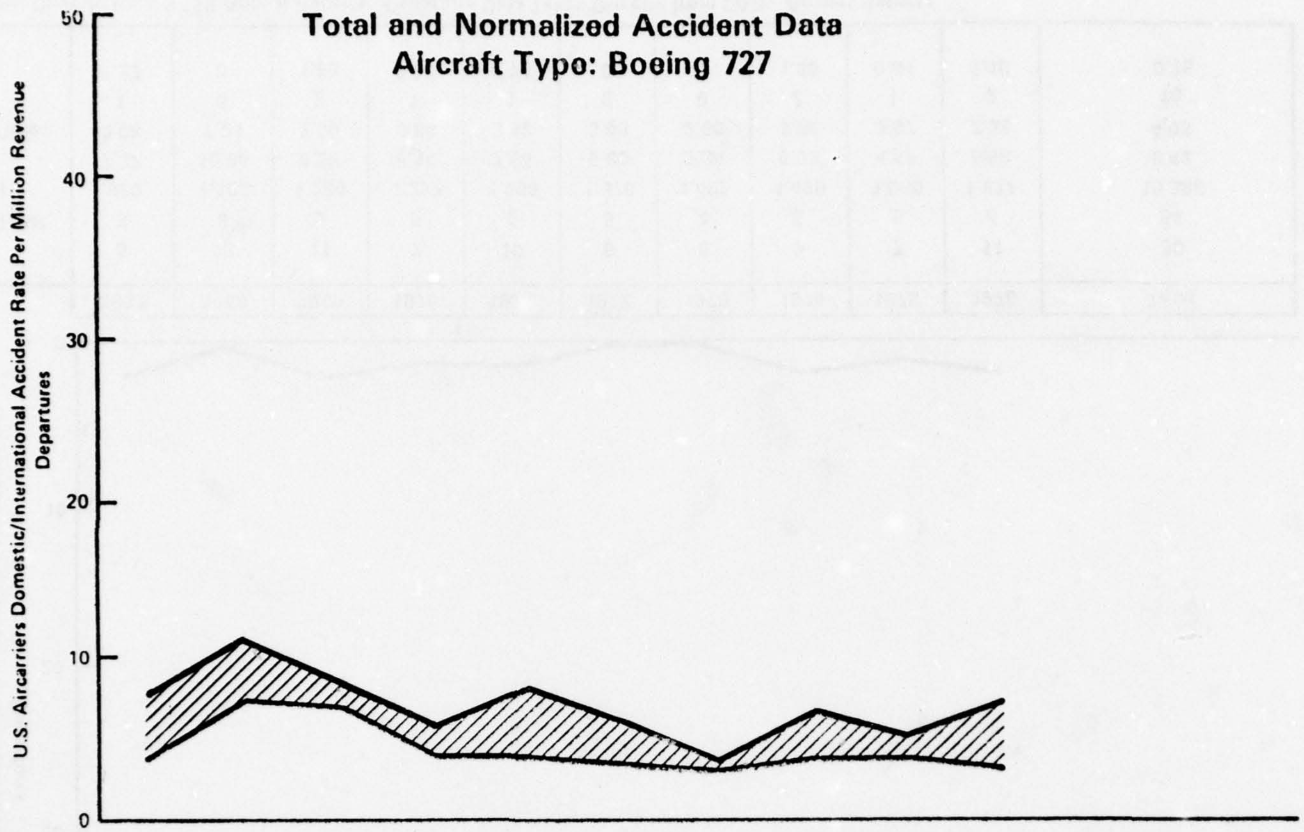
1-0033; 11/21/74; British BAC 1-11

While deplaning, elderly passenger slipped and fell from wet aircraft stair. Aircraft parked engines not operating.

Size of flight deck crew - no factor.

TABLE 7.

Total and Normalized Accident Data
Aircraft Type: Boeing 727



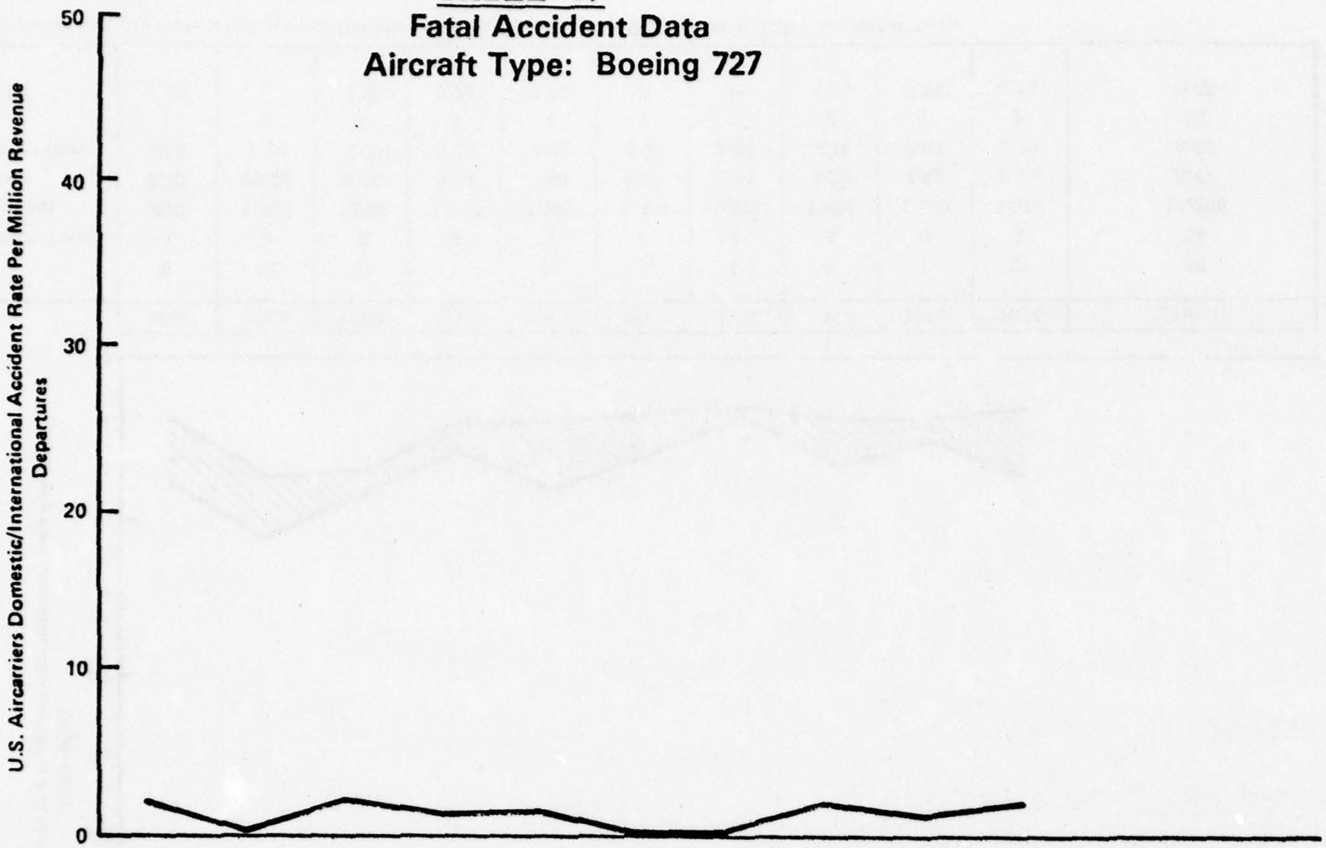
	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	6	12	11	7	10	8	5	9	7	11	86
Normalized Accident Total	3	8	9	5	5	5	4	5	6	4	54
Departures All Services	.820	1.105	1.286	1.287	1.308	1.378	1.495	1.480	1.550	1.677	13.386
Total Accident Rate	7.32	10.86	8.55	5.44	7.64	5.80	3.34	6.08	4.52	6.56	6.42
Normalized Accident Rate	3.66	7.24	7.00	3.88	3.82	3.63	2.66	3.38	3.87	2.38	4.03
Fatal Accidents	1	0	2	1	1	0	0	2	1	2	10
Fatal Accident Rate	1.23	0	1.55	0.78	0.76	0	0	1.35	0.64	1.19	0.75

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 8.

Fatal Accident Data

Aircraft Type: Boeing 727



	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	6	12	11	7	10	8	5	9	7	11	86
Normalized Accident Total	3	8	9	5	5	5	4	5	6	4	54
Departures All Services	.820	1.105	1.286	1.287	1.308	1.378	1.495	1.480	1.550	1.677	13.386
Total Accident Rate	7.32	10.86	8.55	5.44	7.64	5.80	3.34	6.08	4.52	6.56	6.42
Normalized Accident Rate	3.66	7.24	7.00	3.88	3.82	3.63	2.66	3.38	3.87	2.38	4.03
Fatal Accidents	1	0	2	1	1	0	0	2	1	2	10
Fatal Accident Rate	1.23	0	1.55	0.78	0.76	0	0	1.35	0.64	1.19	0.75

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

THESE ACCIDENTS WERE REMOVED FROM RATE
CONSIDERATION IN THE NORMALIZATION PROCESS

1-0013; 3/6/67; Boeing 727

Turbulence in flight, clear air. Seat belt not fastened; seat belt sign was on. One flight attendant was injured.

Size of flight deck crew - no factor.

1-0034; 5/15/67; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt not fastened. PAX out of seat when aircraft encountered turbulence. Seat belt sign on well before turbulence encounter.

Size of flight deck crew - no factor.

1-0057; 6/9/67; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened. Aircraft penetrates isolated thunderstorm cell. PAX were adequately warned. Request to divert delayed by departure control.

Size of flight deck crew - no factor.

1-0027; 7/11/68; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Unable to change ATC clearance. Penetrated cumulus line. Seat belt sign on. Crew and PAX warned. Two flight attendants injured.

Size of flight deck crew - no factor.

1-0050; 4/2/68; Boeing 727

Turbulence in flight, clear air.

Size of flight deck crew - no factor.

1-0067; 10/3/68; Boeing 727

Turbulence. One flight attendant injured.

Size of flight deck crew - no factor.

1-0070; 7/5/68; Boeing 727

Turbulence. One flight attendant injured.

Size of flight deck crew - no factor.

1-0008; 1/14/69; Boeing 727

Driver backed ground power unit into side of aircraft.

Size of flight deck crew - no factor.

1-0015; 2/9/69; Boeing 727

Turbulence in flight, clear air. Seat belt sign on. PAX returning to seat fell and broke ankle.

Size of flight deck crew - no factor.

1-0008; 2/25/70; Boeing 727

Turbulence; seat belt sign on. Aircraft encountered light chop PAX age 78 fell and broke hip while walking in buffet area.

Size of flight deck crew - no factor.

1-0047; 12/22/75; Boeing 727

Turbulence in flight, clear air. Seat belt sign off; seat belt off. Pilot-in-command failed to follow approved procedures, directives, etc. One PAX injured.

Size of flight deck crew - no factor.

1-0002; 1/17/76; Boeing 727

Cargo loader, driver undetermined, ran into lower fuselage. PAX injured using emergency exits. Aircraft parked at Jetway. Engines not operating.

Size of flight deck crew - no factor.

1-0004; 2/22/76; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. Flight attendant injured.

Size of flight deck crew - no factor.

1-0007; 3/3/76; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. One PAX injured.

Size of flight deck crew - no factor.

1-0008; 2/16/76; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. Crew made P.A. announcement of possible turbulence. PAX left seat.

Size of flight deck crew - no factor.

1-0017; 8/8/76; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. PAX left seat unobserved; fell returning from lavatory.

Size of flight deck crew - no factor.

1-0019; 6/12/76; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. Severe in-flight turbulence encountered at FL230 for 3 to 5 seconds. Two flight attendants injured.

Size of flight deck crew - no factor.

1-0021; 8/2/76; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on; seat belt fastened. Infant tossed into overhead and landed in aisle during turbulence, was seated with belt fastened.

Size of flight deck crew - no factor.

1-0038; 11/20/70; Boeing 727

Turbulence in flight, clear air. Seat belt not fastened; seat belt sign on. Flight attendant arose from seat, thrown against armrest, closet, floor; received two broken ribs.

Size of flight deck crew - no factor.

1-0009; 5/14/71; Boeing 727

Turbulence in flight, clear air. Seat belt not fastened; seat belt sign on. Descended from FL310 to FL240 due to moderate chop. Crew and PAX warned. Hit clear air turbulence unforecast for time and area.

Size of flight deck crew - no factor.

1-0024; 12/29/71; Boeing 727

Turbulence in flight, clear air. Seat belt sign on. Crew warned PAX of expected turbulence. Injured PAX was in blue room.

Size of flight deck crew - no factor.

1-0033; 6/8/71; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. PAX left seat for blue room despite crew warning of possible turbulence. Crew received radar vectors due to thunderstorms.

Size of flight deck crew - no factor.

1-0037; 3/29/71; Boeing 727

Turbulence in flight, clear air. Seat belt sign on. Turbulence not forecast. Stewardesses checking PAX seat belts, serving meal. Flight attendant injured.

Size of flight deck crew - no factor.

1-0046; 2/7/71; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Pilot-in-command failed to follow approved procedures, directives, etc. Pilot allowed cabin service in known area of possible turbulence per company policy.

Size of flight deck crew - no factor.

1-0028; 6/28/72; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Flight encountered small cumulus cloud which did not show on weather radar. Seat belt light was on but no signal to flight attendants.

Size of flight deck crew - no factor.

1-0030; 1/10/72; Boeing 727

Turbulence in flight, clear air. Seat belt sign on. Seat belt not fastened. Seat belt signs were on during entire trip. PAX was injured while returning from right aft lavatory.

Size of flight deck crew - no factor.

1-0031; 9/30/72; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Pilot-in-command failed to follow approved procedures, directives, etc. Flew in area of forecast thunderstorm activity.

Size of flight deck crew - no factor.

1-0007; 3/17/73; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Two flight attendants injured. Known thunderstorms in area, observed on radar. Encountered moderate to severe turbulence.

Size of flight deck crew - no factor.

1-0018; 4/1/74; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not secured. Elderly lady broke leg when thrown from seat during turbulence encounter.

Size of flight deck crew - no factor.

1-0036; 12/1/74; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened; seat belt sign on. Flight attendant underestimated First Officer's warning, delayed in returning to seat. Thrown against ceiling.

Size of flight deck crew - no factor.

1-0039; 9/21/74; Boeing 727

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened; seat belt sign on. Cabin attendant left seat to initiate her duties. Fell and sustained broken ankle.

Size of flight deck crew - no factor.

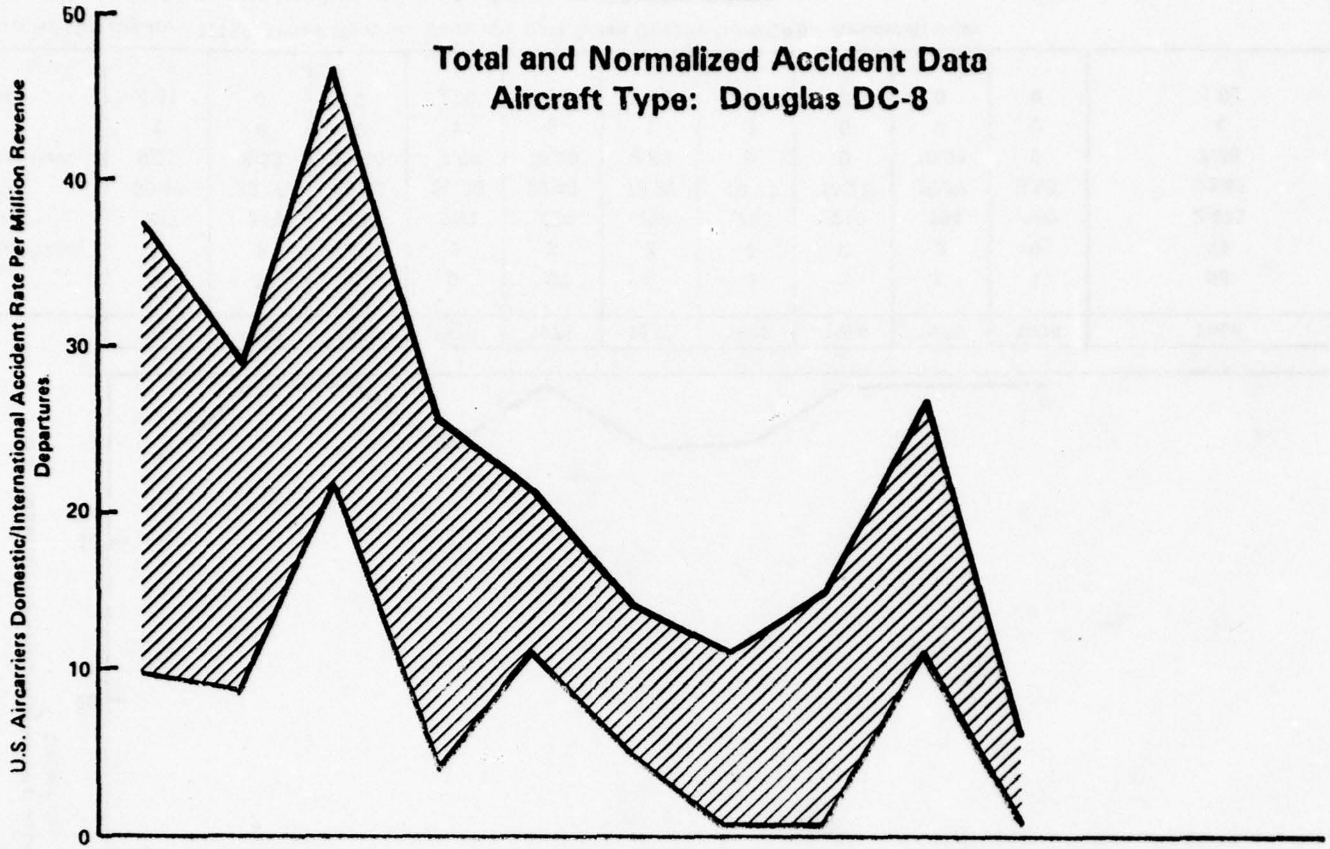
1-0040; 11/17/74; Boeing 727

Turbulence associated with clouds and/or thunderstorms. Seat belt not fastened; seat belt sign on. Two PAX injured. Encountered moderate to heavy turbulence during flight in vicinity of thunderstorm activity. Crew gave ample warning.

Size of flight deck crew - no factor.

TABLE 9.

Total and Normalized Accident Data
Aircraft Type: Douglas DC-8



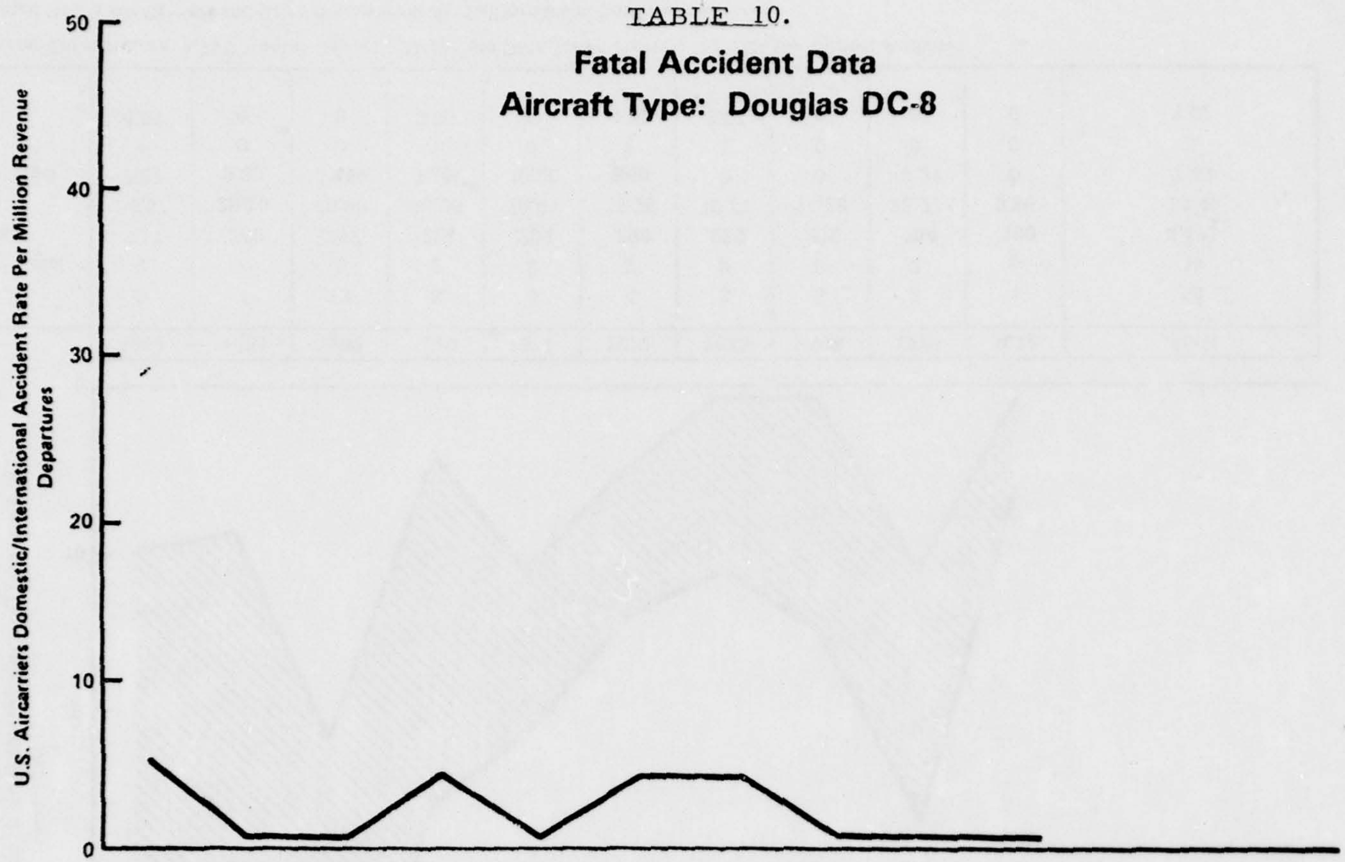
	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	8	7	13	8	6	4	3	3	5	1	58
Normalized Accident Total	2	2	6	2	3	2	0	0	2	0	19
Departures All Services	.217	.240	.277	.282	.294	.299	.280	.210	.194	.180	2.473
Total Accident Rate	36.87	29.16	46.93	28.36	20.41	13.38	10.71	14.28	25.77	5.55	23.45
Normalized Accident Rate	9.22	8.33	21.66	7.09	10.20	6.69	0	0	10.31	0	7.68
Fatal Accidents	1	0	0	1	0	1	1	0	0	0	4
Fatal Accident Rate	4.61	0	0	3.55	0	3.34	3.57	0	0	0	1.62

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 10.

Fatal Accident Data

Aircraft Type: Douglas DC-8



	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	8	7	13	8	6	4	3	3	5	1	58
Normalized Accident Total	2	2	6	2	3	2	0	0	2	0	19
Departures All Services	.217	.240	.277	.282	.294	.299	.280	.210	.194	.180	2.473
Total Accident Rate	36.87	29.16	46.93	28.36	20.41	13.38	10.71	14.28	25.77	5.55	23.47
Normalized Accident Rate	9.22	8.33	21.66	7.09	10.20	6.69	0	0	10.31	0	7.68
Fatal Accidents	1	0	0	1	0	1	1	0	0	0	4
Fatal Accident Rate	4.61	0	0	3.55	0	3.34	3.57	0	0	0	1.62

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

THESE ACCIDENTS WERE REMOVED FROM RATE
CONSIDERATION IN THE NORMALIZATION PROCESS

1-0016; 4/4/67; Douglas DC-8

Turbulence, associated with clouds and thunderstorms, seat belt sign on while PAX in lavatory - PAX fell, broke leg returning to seat.

Size of flight deck crew - no factor.

1-0017; 5/1/67; Douglas DC-8

Stewardess wearing high heel shoes lost her balance and fell, broke ankle. Very light turbulence.

Size of flight deck crew - no factor.

1-0030; 6/9/67; Douglas DC-8

Thunderstorm activity. Flight attendants injured while performing flight duties.

Size of flight deck crew - no factor.

1-0039; 8/30/67; Douglas DC-8

Pilot-in-command failed to follow approved procedures, directives, etc. Turbulence, associated with clouds, thunderstorms, pilot failed to divert around clouds on advice of ground radar. Seat belt sign off. PAX injured.

Size of flight crew - no factor.

1-0041; 10/1/67; Douglas DC-8

Turbulence in flight, clear and associated with clouds, thunderstorms. Seat belt sign on, PAX warned by crew. PAX failed to remain in seat.

Size of flight deck crew - no factor.

1-0049; 8/25/67; Douglas DC-8

Turbulence in-flight clear. Seat belt sign off. Weather slightly worse than forecast.

Size of flight deck crew - no factor.

1-0022; 8/14/68; Douglas DC-8

Turbulence in flight, clear air. Seat belt sign off. PAX fell in aisle, fractured left foot.

Size of flight deck crew - no factor.

1-0053; 1/28/68; Douglas DC-8

Turbulence in flight, clear air PAX injured. Crew stated both announcement made and seat belt sign on.

Size of flight deck crew - no factor.

1-0066; 8/6/68; Douglas DC-8

Turbulence, associated with clouds, thunderstorms. Ground and aircraft radar did not show cell. Weather forecast inaccurate. PAX injured.

Size of flight deck crew - no factor.

1-0068; 1/25/68; Douglas DC-8

Turbulence, associated with clouds, thunderstorms. Ground and aircraft radar did not show cell. Weather forecast inaccurate. PAX injured.

Size of flight deck crew - no factor.

1-0069; 6/12/68; Douglas DC-8

Turbulence associated with clouds and thunderstorms. Pilot-in-command failed to follow approved procedures, directives, etc. Seat belt sign on. PAX injured.

Size of flight deck crew - no factor.

1-0012; 3/16/69; Douglas DC-8

Turbulence in flight, clear air. Seat belt sign was on. Stewardess thrown to ceiling while in aisle.

Size of flight deck crew - no factor.

1-0018; 4/27/69; Douglas DC-8

Turbulence. Associated with clouds, thunderstorms. Pilot-in-command failed to follow approved procedures, directives, etc. Seat belt sign on. Pilot gave crew and PAX ample warning, but did not slow aircraft to company max thunderstorm penetration speed. Six PAX injured.

Size of flight deck crew - no factor.

1-0019; 4/27/69; Douglas DC-8

Turbulence, associated with clouds, thunderstorm. Seat belt sign on. Radar inoperative. Pilot warned flight attendants, but they did not check PAX seat belts. Eight PAX were injured.

Size of flight deck crew - no factor.

1-0030; 7/22/69; Douglas DC-8

Turbulence associated with clouds, thunderstorms. Pilot-in-command failed to follow approved procedures, directives, etc. Seat belt sign was turned on. Beverage service in progress.

Size of flight deck crew - no factor.

1-0031; 8/2/69; Douglas DC-8

Turbulence, associated with clouds, thunderstorms. Seat belt sign on. PAX injured while returning from Blue Room.

Size of flight deck crew - no factor.

1-0038; 7/23/69; Douglas DC-8

Turbulence. In flight clear air. Pilot-in-command failed to follow approved procedures, directives, etc. Seat belt sign turned on too late. Thunderstorm and cumulus build-ups in area.

Size of flight deck crew - no factor.

1-0047; 8/2/69; Douglas DC-8

Turbulence associated with clouds, thunderstorms. Seat belt sign on. Pilot requested vector around storm. ATC radar was inoperative. Stewardess inadvertently released seat belt.

Size of flight deck crew - no factor.

1-0004; 3/18/70; Douglas DC-8

Turbulence in flight, clear air. Seat belt sign off. PAX fell and broke ankle.

Size of flight deck crew - no factor.

1-0009; 5/29/70; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Pilot-in-command failed to follow approved procedures, directives, etc. Seat belt sign on. Aircraft was deviating south of course between two large build-ups. Warning to flight attendants was late. Flight attendant injured.

Size of flight deck crew - no factor.

1-0013; 4/20/70; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on. Pilot was steering around build-ups showing on aircraft radar. Crew gave adequate warning of turbulence.

Size of flight deck crew - no factor.

1-0022; 5/27/70; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. Two flight attendants and one PAX injured. Pilot-in-command failed to follow approved procedures, directives, etc. Flight in thunderstorm area. Aircraft radar inoperative. Pilot was receiving steers but didn't notify ATC that radar was inoperative.

Size of flight deck crew - no factor.

1-0031; 8/15/70; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorm. Seat belt sign on; seat belt not fastened. Controller turned aircraft into thunderstorm. Pilot had requested deviation. Controller decision influenced by heavy sector workload. Two flight attendants injured.

Size of flight deck crew - no factor.

1-0034; 9/21/70; Douglas DC-8

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. One PAX and one flight attendant injured.

Size of flight deck crew - no factor.

1-0028; 1/3/71; Douglas DC-8

Turbulence in flight, clear air forecast substantial correct. Seat belt sign off. Pilot-in-command failed to follow approved procedures, directives, etc. Encountered forecast clear air turbulence at FL370 100 mi. east of Kansas City, Mo. Captain had checked other flights and centers, no turbulence reported.

Size of flight deck crew - no factor.

1-0034; 7/26/71; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened. Weather radar did not show return. Flight above broken to overcast deck. One flight attendant injured.

Size of flight deck crew - no factor.

1-0045; 12/23/71; Douglas DC-8

Turbulence in flight clear air. Seat belt off; seat belt sign off. Encountered turbulence with no warning or indication. Autopilot engaged. One flight attendant injured.

Size of flight deck crew - no factor.

1-0019; 2/26/72; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened. Seat belt sign on. One PAX inadvertently released seat belt and was thrown from seat. One PAX was hit by a flying object.

Size of flight deck crew - no factor.

1-0042; 5/7/72; Douglas DC-8

Turbulence in flight clear air. Seat belt sign off. Unforecasted clear air turbulence.

Size of flight deck crew - no factor.

1-0002; 2/28/73; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened; seat belt sign on. One flight attendant injured.

Size of flight deck crew - no factor.

1-0021; 8/20/73; Douglas DC-8

Turbulence in flight clear air. Seat belt not fastened; seat belt sign on. One PAX injured.

Size of flight deck crew - no factor.

1-0027; 10/8/73; Douglas DC-8

Ground crewman run over by nose gear during push back from gate. Investigation under jurisdiction of Gov't of Japan.

Size of flight crew - no factor.

1-0022; 7/27/74; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened; seat belt sign on. Injuries to PAX and flight attendants not secured by seat belts. Flight attendant thrown from left aft flight attendant seat; seat belt opened.

Size of flight deck crew - no factor.

1-0034; 11/6/74; Douglas DC-8

Turbulence in flight, clear air. Seat belt sign off. As seat belt sign was turned off, elderly PAX left seat. Brief turbulence encountered. PAX fell and injured ankle.

Size of flight deck crew - no factor.

1-0043; 12/5/75; Douglas DC-8

Turbulence, associated with clouds and/or thunderstorms. Seat belt not fastened. Seat belt sign on. Crew gave both visual and oral warnings.

Size of flight deck crew - no factor.

1-0004; 3/21/75; Douglas DC-8

Turbulence in flight, clear air. Seat belt not fastened; seat belt sign off. One flight attendant injured.

Size of flight deck crew - no factor.

1-0015; 8/8/75; Douglas DC-8

Turbulence in flight, clear air. Seat belt not fastened; seat belt sign off. No clear air turbulence. Encountered clear air turbulence and flight attendant was thrown from jump seat which folded. After encounter, flight attendant struck seat.

Size of flight deck crew - no factor.

1-0028; 9/22/75; Douglas DC-8

Turbulence. Encountered wake vortex from L-1011 which crossed VORTAC at approximately same altitude about 3 minutes prior.

Size of flight deck crew - no factor.

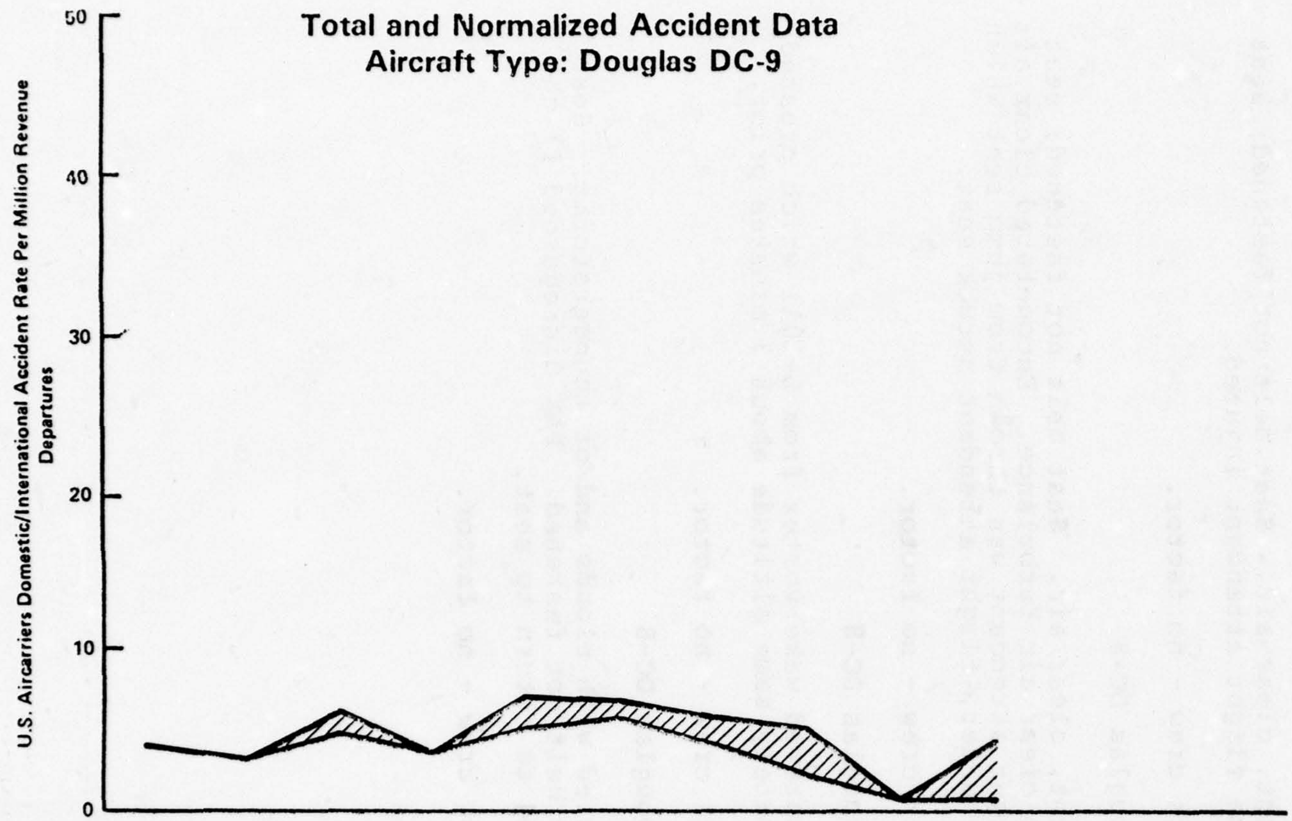
1-0013; 5/27/76; Douglas DC-8

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on; seat belt not fastened. PAX disregarded flight attendant's warning to return to seat.

Size of flight deck crew - no factor.

TABLE 11.

Total and Normalized Accident Data
Aircraft Type: Douglas DC-9

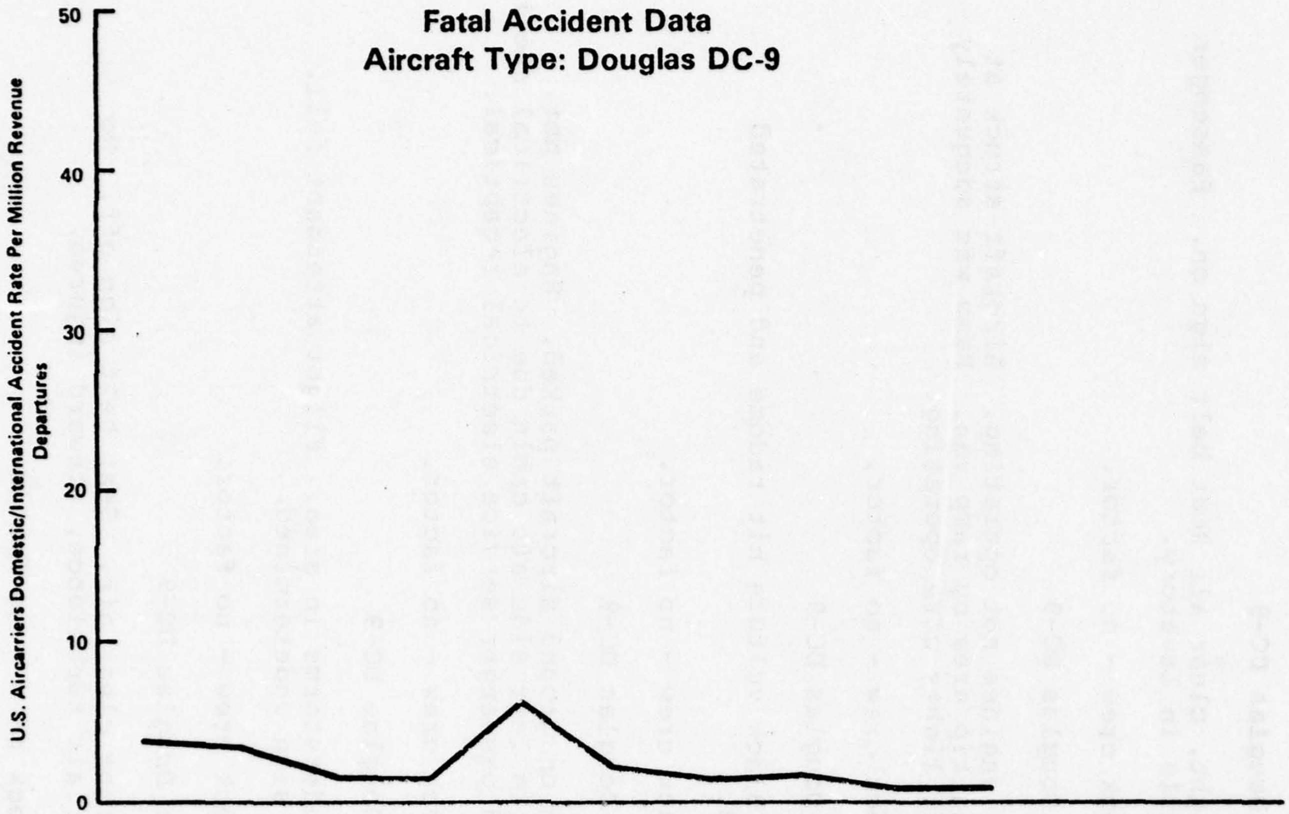


	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	1	2	6	3	7	7	6	5	0	4	41
Normalized Accident Total	1	2	5	3	5	6	4	2	0	4	32
Departures All Services	.319	.710	1.018	1.099	1.139	1.166	1.161	1.114	1.107	1.174	10.007
Total Accident Rate	3.13	2.92	5.89	2.73	6.15	6.00	5.17	4.49	0	3.41	4.10
Normalized Accident Rate	3.13	2.92	4.91	2.73	4.39	5.15	3.44	1.79	0	3.41	3.20
Fatal Accidents	1	1	1	1	3	2	1	1	0	0	11
Fatal Accident Rate	3.13	1.41	0.98	0.91	2.63	1.71	0.86	0.90	0	0	1.10

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 12.

Fatal Accident Data
Aircraft Type: Douglas DC-9



	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	1	2	6	3	7	7	6	5	0	4	41
Normalized Accident Total	1	2	5	3	5	6	4	2	0	4	32
Departures All Services	.319	.710	1.018	1.099	1.139	1.166	1.161	1.114	1.107	1.174	10.007
Total Accident Rate	3.13	2.92	5.89	2.73	6.15	6.00	5.17	4.49	0	3.41	4.10
Normalized Accident Rate	3.13	2.92	4.91	2.73	4.39	5.15	3.44	1.79	0	3.41	3.20
Fatal Accidents	1	1	1	1	3	2	1	1	0	0	11
Fatal Accident Rate	3.13	1.41	0.98	0.91	2.63	1.71	0.86	0.90	0	0	1.10

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

THESE ACCIDENTS WERE REMOVED FROM RATE
CONSIDERATION IN THE NORMALIZATION PROCESS

1-0057; 4/24/69; Douglas DC-9

Turbulence in flight, clear air seat belt sign on. Passenger fractured knee while in lavatory.

Size of flight deck crew - no factor.

1-0022; 10/9/71; Douglas DC-9

Aircraft parked - engines not operating. Aircraft struck at rear of right wing tip area by ramp van. Ramp was adequately lighted. Aircraft lights were operating.

Size of flight deck crew - no factor.

1-0036; 8/18/71; Douglas DC-9

Bird collision. Black vulture hit radome and penetrated pressure bulkhead.

Size of flight deck crew - no factor.

1-0018; 5/10/72; Douglas DC-9

Fire or explosion on ground aircraft parked. Engines not operating - fire in left side aft cabin due to electrical short circuit in unused passenger service electrical receptical.

Size of flight deck crew - no factor.

1-0004; 4/1/73; Douglas DC-9

Turbulence. Thunderstorms in area. Flight attendant fell. Use of seat belt sign undetermined.

Size of flight deck crew - no factor.

1-0031; 12/21/73; Douglas DC-9

Turbulence in-flight clear air. Seat belt sign off. No forecast of clear air turbulence, steward injured.

Size of flight deck crew - no factor.

1-0003; 2/15/74; Douglas DC-9

Turbulence in flight clear air. Seat belt sign on. Seat belt off. Flight attendant in rear galley thrown against ceiling, fell to floor.

Size of flight deck crew - no factor.

1-0010; 9/1/74; Douglas DC-9

Turbulence. Seat belt sign on. Seat belt off. P/A announcement made prior to turbulence encounter. Flight attendant injured trying to hold service cart down.

Size of flight deck crew - no factor.

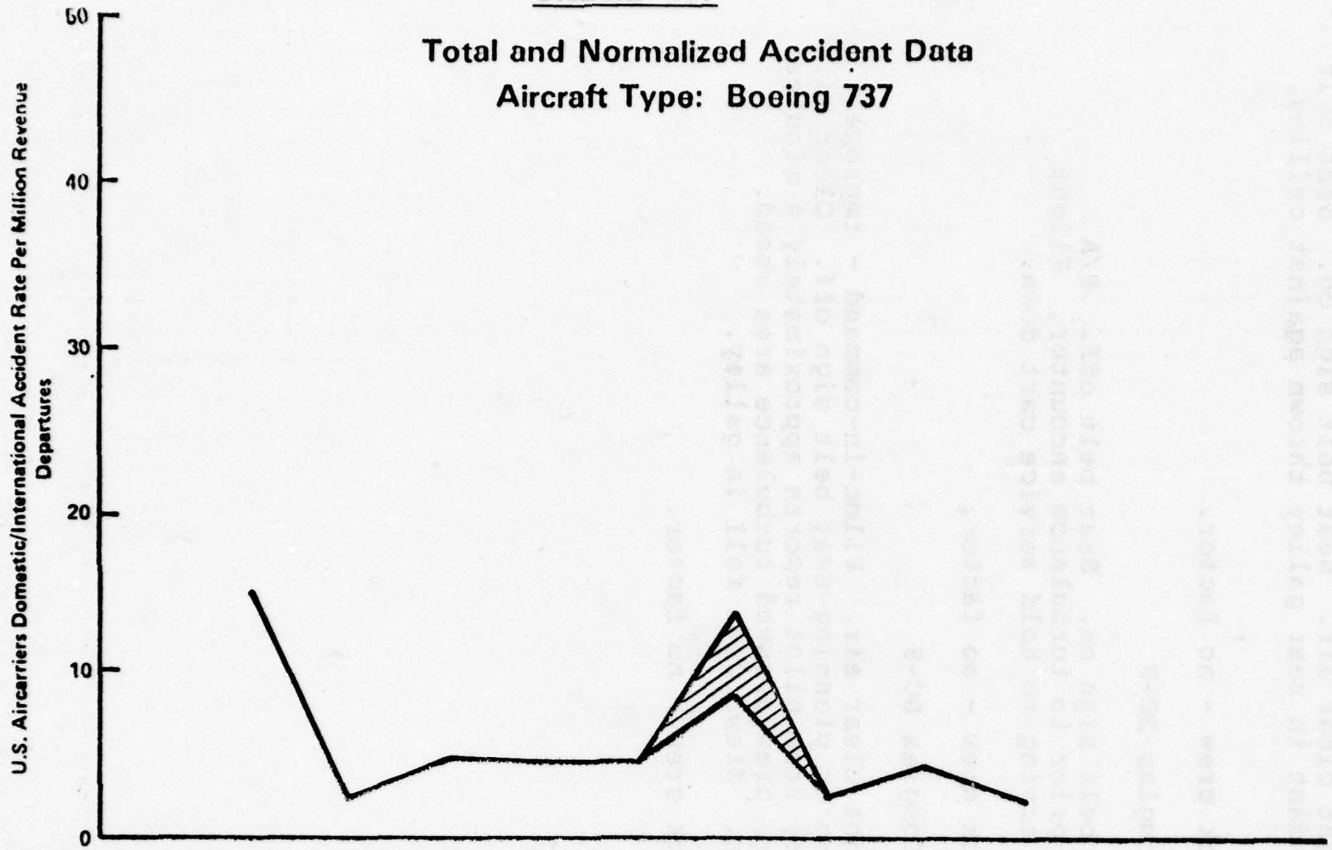
1-0015; 2/21/74; Douglas DC-9

Turbulence in flight clear air. Pilot-in-command - improper in-flight decisions or planning-seat belt sign off. Clear air turbulence advisory from pilot reports approximately 4 minutes prior to encounter, crew assumed turbulence area ahead. Airspeed 340 knots. Stewardess fell in galley.

Size of flight deck crew - no factor.

TABLE 13.

Total and Normalized Accident Data
Aircraft Type: Boeing 737



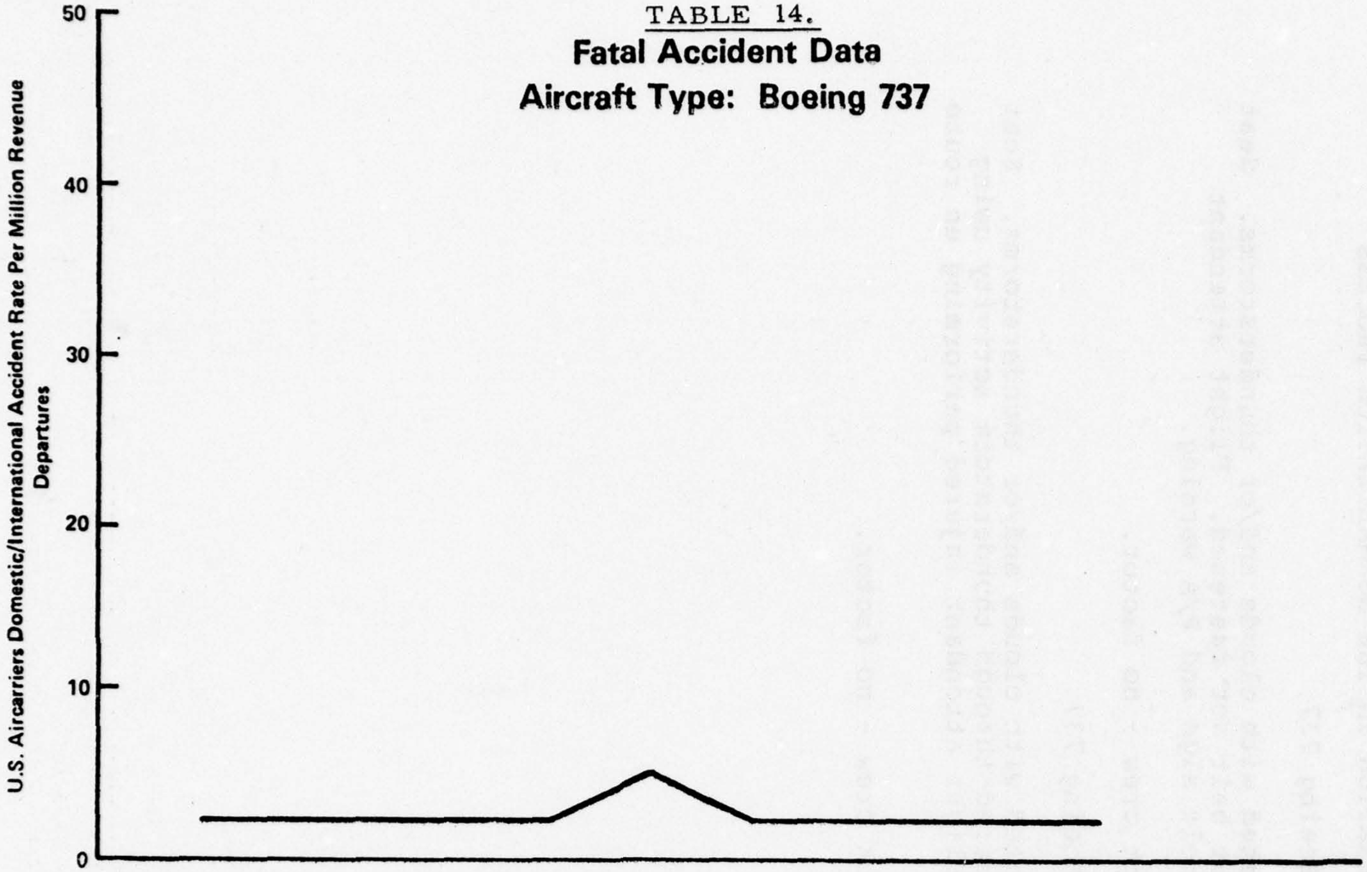
	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	–	1	0	1	1	1	5	0	1	0	10
Normalized Accident Total	–	1	0	1	1	1	3	0	1	0	8
Departures All Services	–	.079	.325	.374	.373	.393	.420	.410	.405	4.33	3.212
Total Accident Rate	–	12.66	0	2.67	2.68	2.54	11.88	0	2.47	0	3.11
Normalized Accident Rate	–	12.66	0	2.67	2.68	2.54	7.13	0	2.47	0	2.49
Fatal Accidents	–	0	0	0	0	1	0	0	0	0	1
Fatal Accident Rate	–	0	0	0	0	2.54	0	0	0	0	.31

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 14.

Fatal Accident Data

Aircraft Type: Boeing 737



	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	–	1	0	1	1	1	5	0	1	0	10
Normalized Accident Total	–	1	0	1	1	1	3	0	1	0	8
Departures All Services	–	.079	.325	.374	.373	.393	.420	.410	.405	.433	3.212
Total Accident Rate	–	12.66	0	2.67	2.68	2.54	11.88	0	2.47	0	3.11
Normalized Accident Rate	–	12.66	0	2.67	2.68	2.54	7.13	0	2.47	0	2.49
Fatal Accidents	–	0	0	0	0	1	0	0	0	0	0
Fatal Accident Rate	–	0	0	0	0	2.54	0	0	0	0	.31

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB–Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

THESE ACCIDENTS WERE REMOVED FROM RATE CONSIDERATION IN THE NORMALIZATION PROCESS

1-0016; 6/29/73; Boeing 737

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Seat belt not fastened. Flight attendant disregarded seat belt sign and P/A warning.

Size of flight deck crew - no factor.

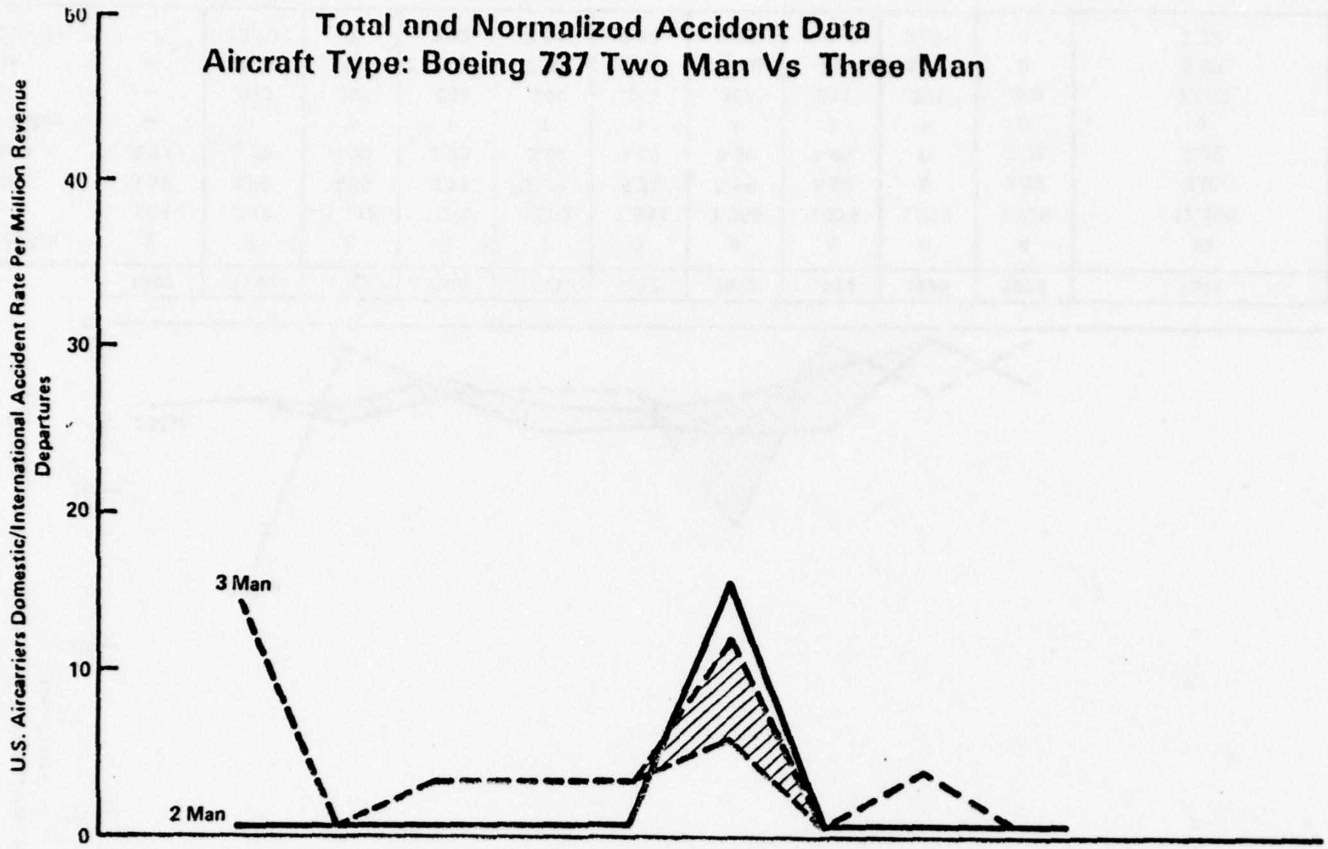
1-0013; 7/24/73; Boeing 737

Turbulence associated with clouds and/or thunderstorms. Seat belt sign on. Steered through thunderstorm activity using airborne radar. Flight attendant injured performing en route duties.

Size of flight deck crew - no factor.

TABLE 15.

Total and Normalized Accident Data
Aircraft Type: Boeing 737 Two Man Vs Three Man

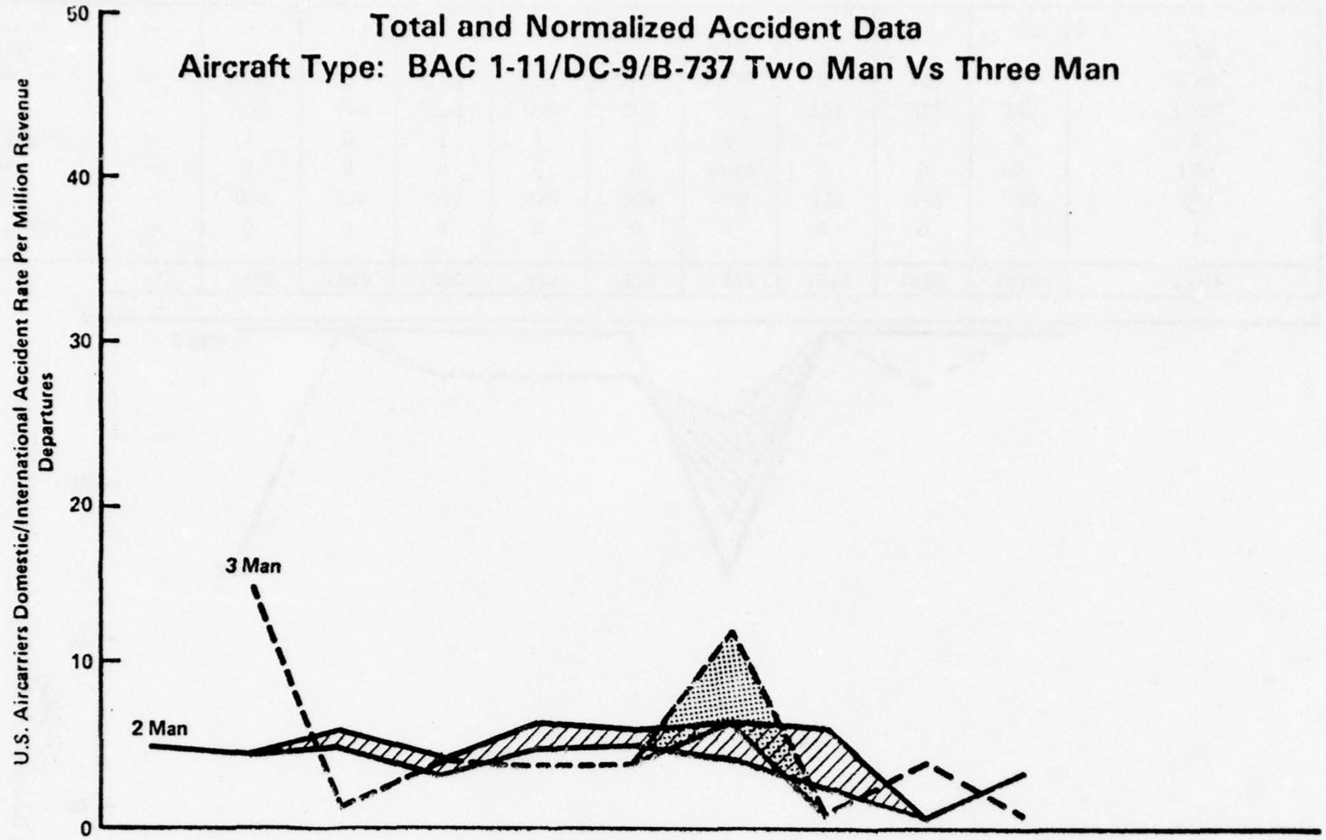


	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents – 2 Man	–	0	0	0	0	0	1	0	0	0	1
Departures	–	.006	.021	.020	.033	.038	.069	.139	.153	.165	.644
Total Accident Rate	–	0	0	0	0	0	14.49	0	0	0	1.55
Total Accidents – 3 Man	–	1	0	1	1	1	4	0	1	0	9
Departures	–	.073	.304	.354	.340	.355	.351	.271	.252	.268	2.568
Total Accident Rate	–	13.70	0	2.82	2.94	2.82	11.36	0	3.97	0	3.50
Normalized Acc. Rate							5.68				2.72

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 16.

Total and Normalized Accident Data
Aircraft Type: BAC 1-11/DC-9/B-737 Two Man Vs Three Man

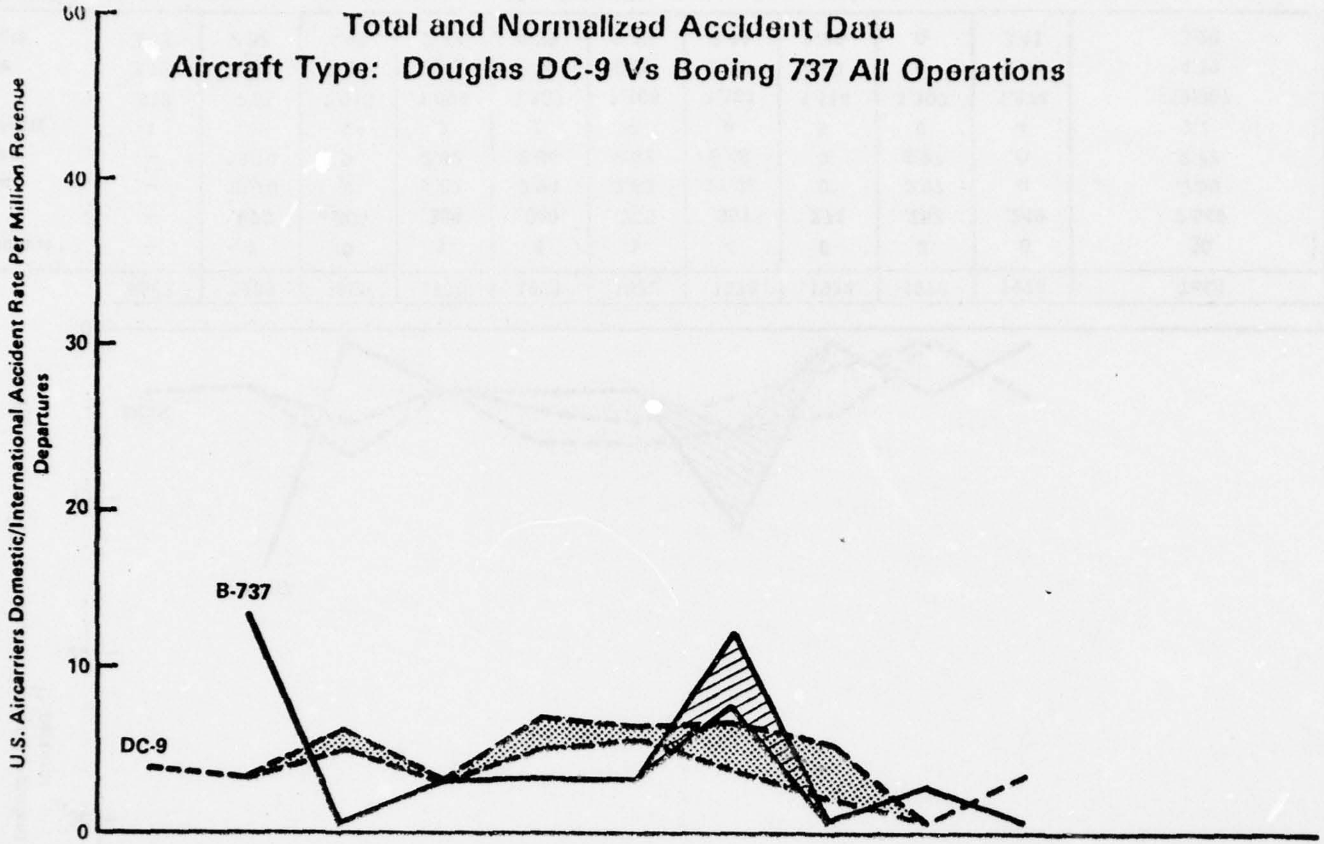


	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents – 2 Man	2	3	6	4	7	7	8	8	0	4	49
Departures	.504	.912	1.242	1.285	1.302	1.333	1.358	1.374	1.375	1.720	12.405
Total Accident Rate	3.97	3.29	4.83	3.11	5.38	5.25	5.89	5.82	0	2.32	3.95
Normalized Acc. Rate	3.97	3.29	4.03	2.33	3.84	4.50	3.68	1.46	0	2.32	2.82
Total Accidents – 3 Man	–	1	0	1	1	1	4	0	1	0	9
Departures	–	.073	.304	.354	.340	.355	.352	.271	.251	.268	2.568
Total Accident Rate	–	13.70	0	2.82	2.94	2.82	11.36	0	3.97	0	3.50
Normalized Acc. Rate	–	13.70	0	2.82	2.94	2.82	5.68	0	3.97	0	2.72

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 17.

Total and Normalized Accident Data
Aircraft Type: Douglas DC-9 Vs Boeing 737 All Operations



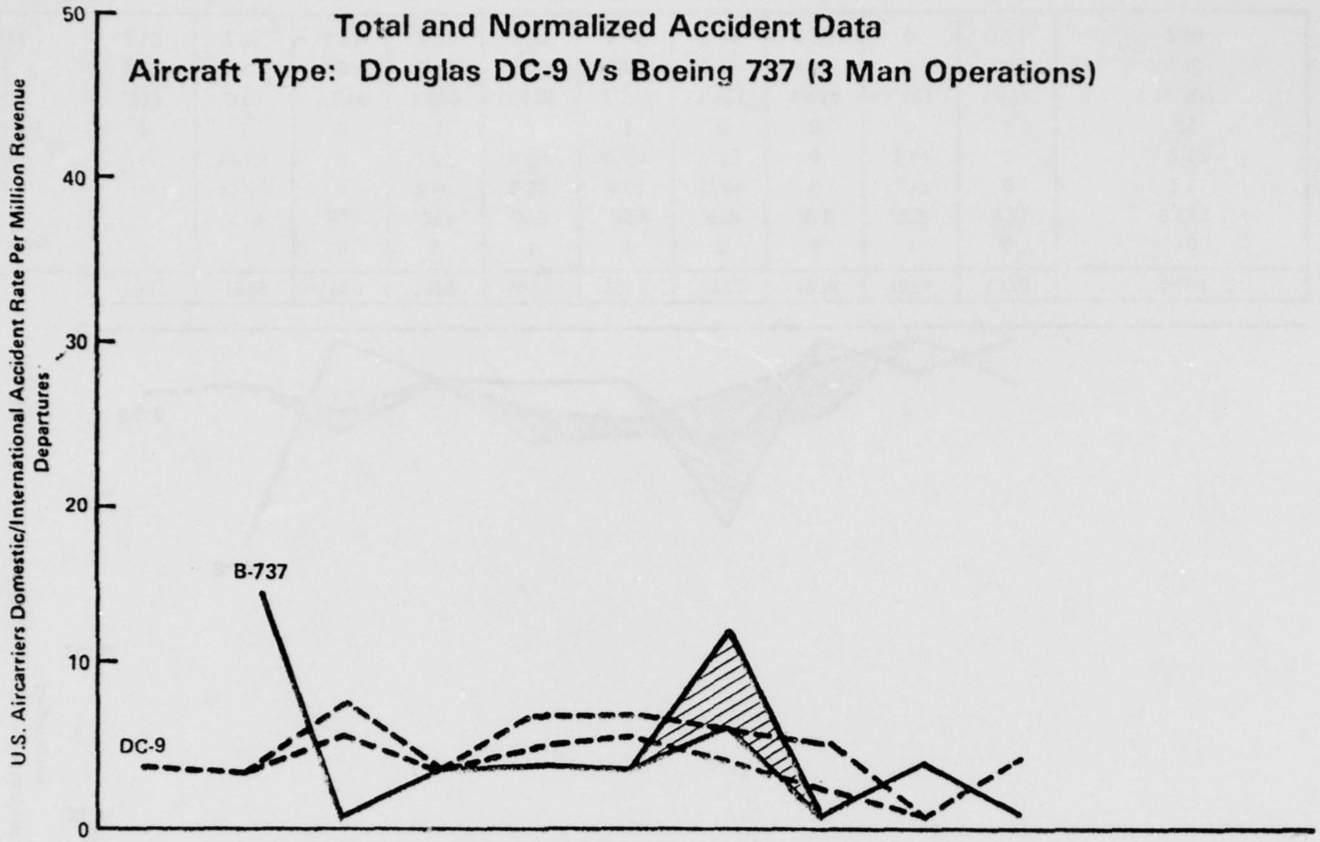
	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
B-737 – Total Accidents	–	1	0	1	1	1	5	0	1	0	10
Departures	–	.079	.325	.374	.373	.393	.420	.410	.405	.433	3.212
Total Accident Rate	–	12.66	0	2.67	2.68	2.54	11.88	0	2.47	0	3.11
Normalized Acc. Rate	–	12.66	0	2.67	2.68	2.54	7.13	0	2.47	0	2.49
DC-9 – Total Accidents	1	2	6	3	7	7	6	5	0	4	41
Departures	.319	.710	1.018	1.099	1.139	1.166	1.161	1.114	1.107	1.174	10.007
Total Accident Rate	3.13	2.92	5.89	2.73	6.15	6.00	5.17	4.49	0	3.41	4.10
Normalized Acc. Rate	3.13	2.92	4.91	2.73	4.39	5.15	3.44	1.79	0	3.41	3.20

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 18.

Total and Normalized Accident Data

Aircraft Type: Douglas DC-9 Vs Boeing 737 (3 Man Operations)



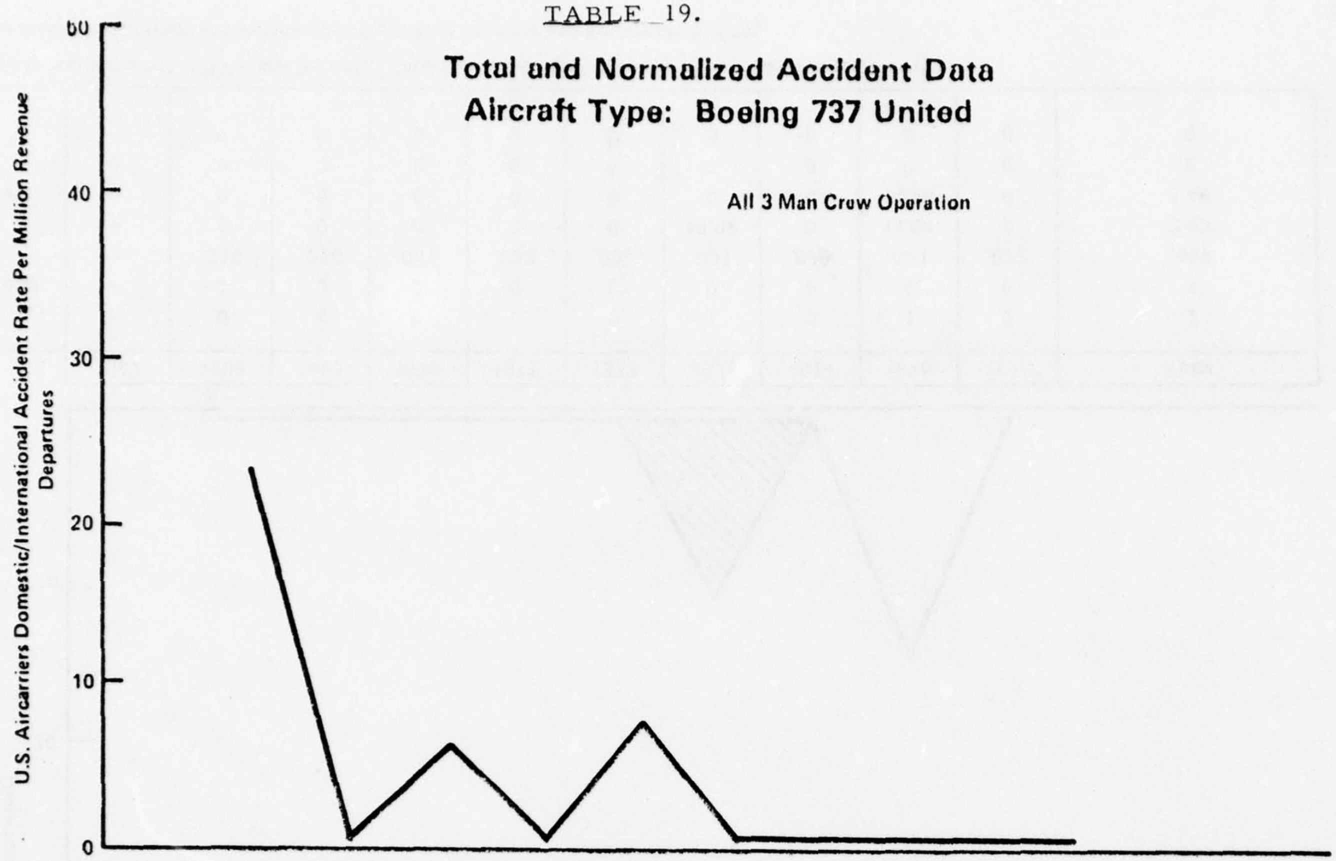
	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
B-737 – Total Accidents	–	1	0	1	1	1	4	0	2	0	10
Departures	–	.073	.304	.354	.340	.355	.351	.271	.252	.249	2.568
Total Accident Rate	–	13.70	0	2.82	2.94	2.82	11.36	0	3.97	0	3.50
Normalized Acc. Rate	–	13.70	0	2.82	2.94	2.82	5.68	0	3.97	0	2.72
DC-9 – Total Accidents	1	2	6	3	7	7	6	5	0	4	41
Departures	.319	.710	1.018	1.099	1.139	1.166	1.161	1.114	1.107	1.174	10.007
Total Accident Rate	3.13	2.92	5.89	2.73	6.15	6.00	5.17	4.49	0	3.41	4.10
Normalized Acc. Rate	3.13	2.92	4.91	2.73	4.39	5.15	3.44	1.79	0	3.41	3.20

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 19.

Total and Normalized Accident Data
Aircraft Type: Boeing 737 United

All 3 Man Crew Operation

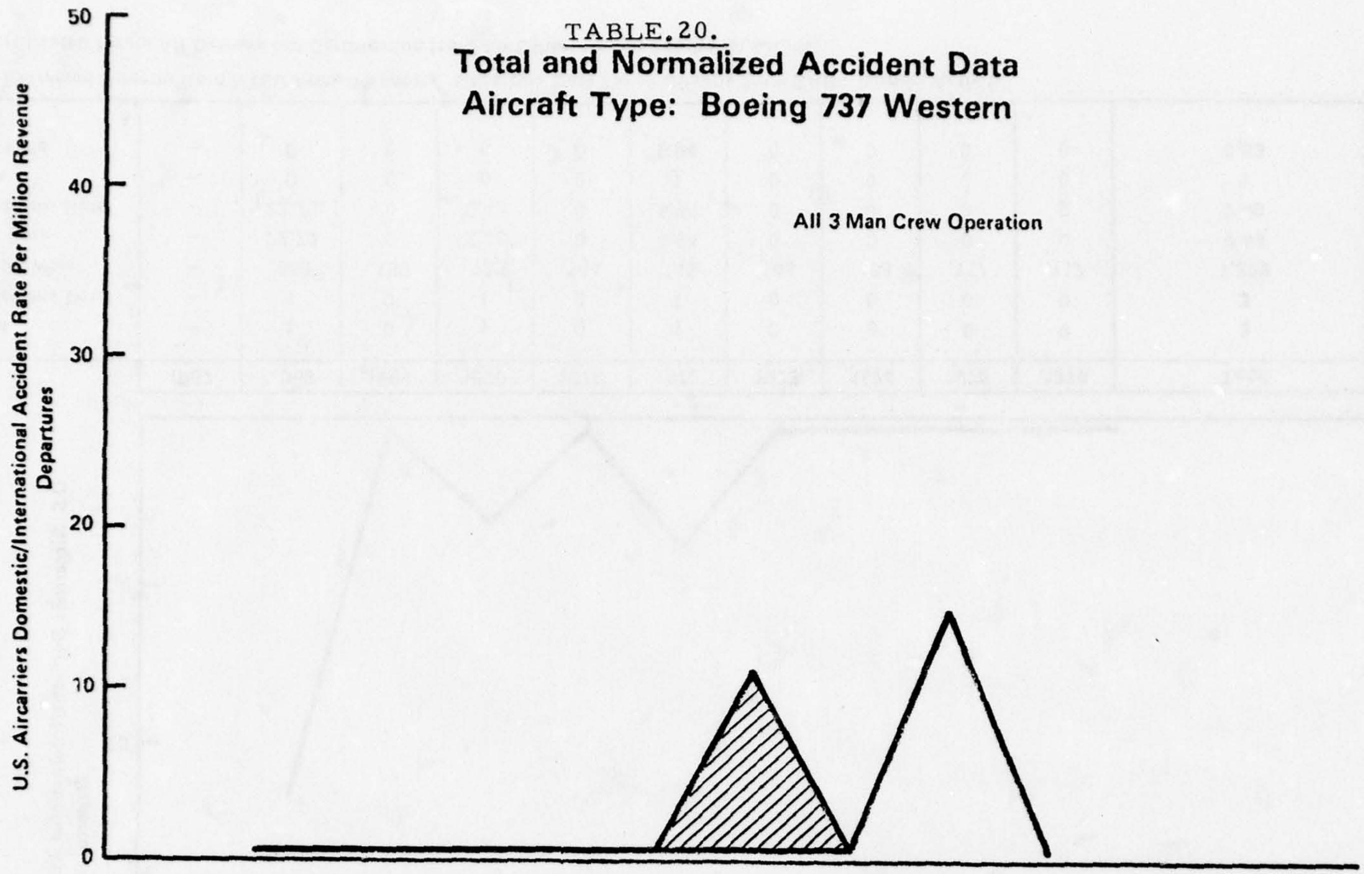


	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	–	1	0	1	0	1	0	0	0	0	3
Normalized Accident Total	–	1	0	1	0	1	0	0	0	0	3
Departures All Services	–	.045	.165	.185	.144	.145	.146	.138	.117	.117	1.202
Total Accident Rate	–	22.73	0	5.43	0	6.94	0	0	0	0	2.49
Normalized Accident Rate	–	22.73	0	5.43	0	6.94	0	0	0	0	2.49
Fatal Accidents	–	0	0	0	0	1	0	0	0	0	1
Fatal Accident Rate	–	0	0	0	0	6.94	0	0	0	0	0.83

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE. 20.

Total and Normalized Accident Data
Aircraft Type: Boeing 737 Western

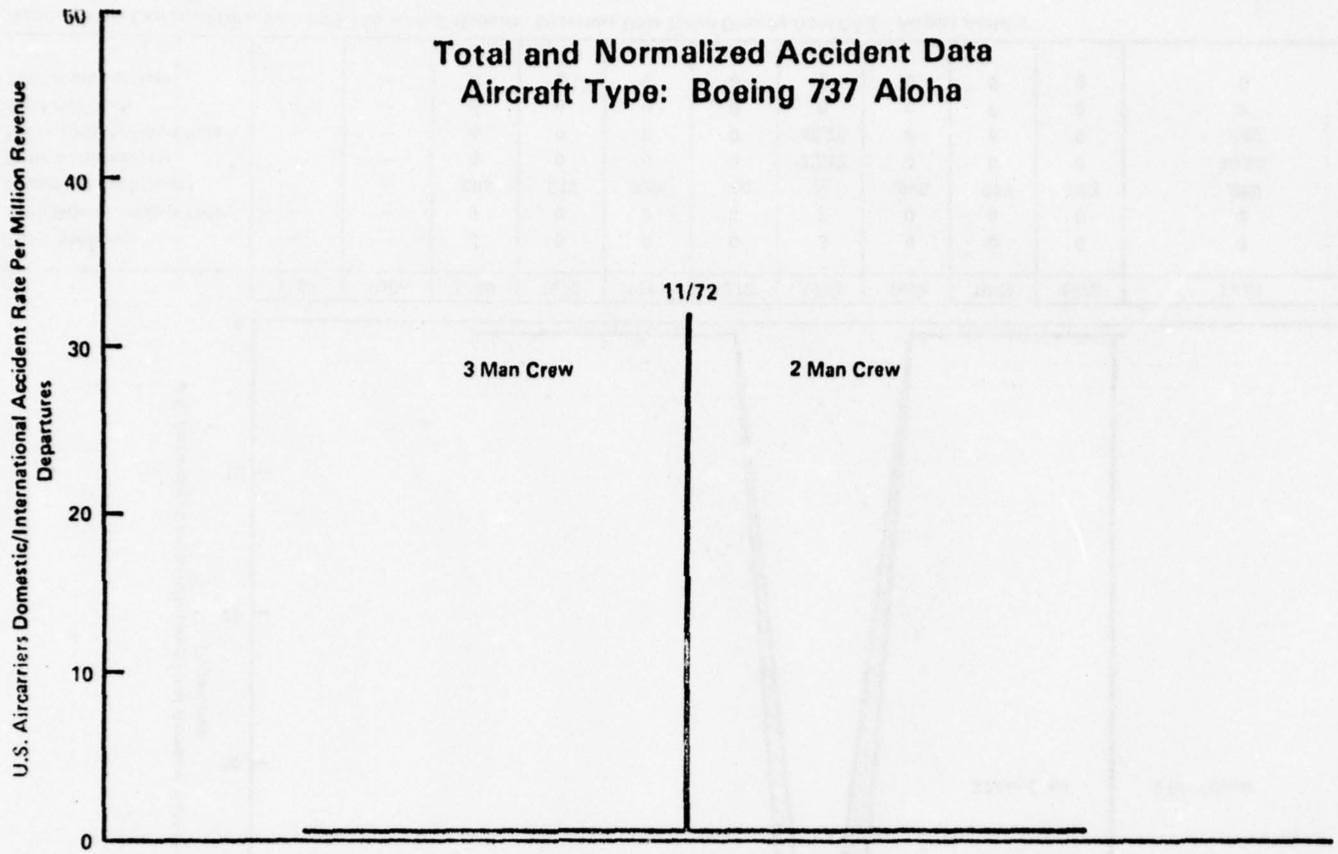


	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	–	0	0	0	0	0	1	0	1	0	2
Normalized Accident Total	–	0	0	0	0	0	0	0	1	0	1
Departures All Services	–	.019	.076	.081	.088	.090	.091	.079	.071	.072	.667
Total Accident Rate	–	0	0	0	0	0	10.99	0	14.08	0	2.99
Normalized Accident Rate	–	0	0	0	0	0	0	0	14.08	0	1.49
Fatal Accidents	–	0	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	0	0	0	0	0	0	0	0	0	0

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 21.

Total and Normalized Accident Data
Aircraft Type: Boeing 737 Aloha

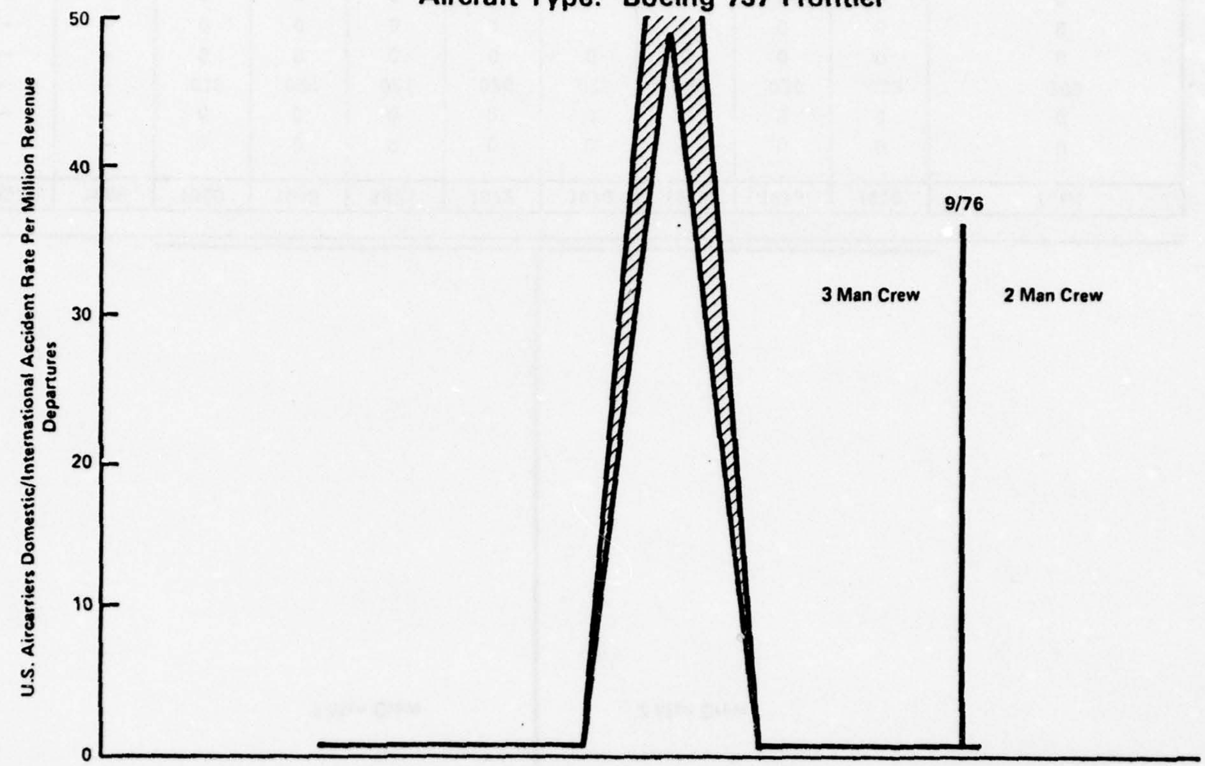


	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	–	–	0	0	0	0	0	0	0	0	0
Normalized Accident Total	–	–	0	0	0	0	0	0	0	0	0
Departures All Services	–	–	.019	.021	.021	.026	.029	.030	.030	.033	.209
Total Accident Rate	–	–	0	0	0	0	0	0	0	0	0
Normalized Accident Rate	–	–	0	0	0	0	0	0	0	0	0
Fatal Accidents	–	–	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	–	0	0	0	0	0	0	0	0	0

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 22.

Total and Normalized Accident Data
Aircraft Type: Boeing 737 Frontier

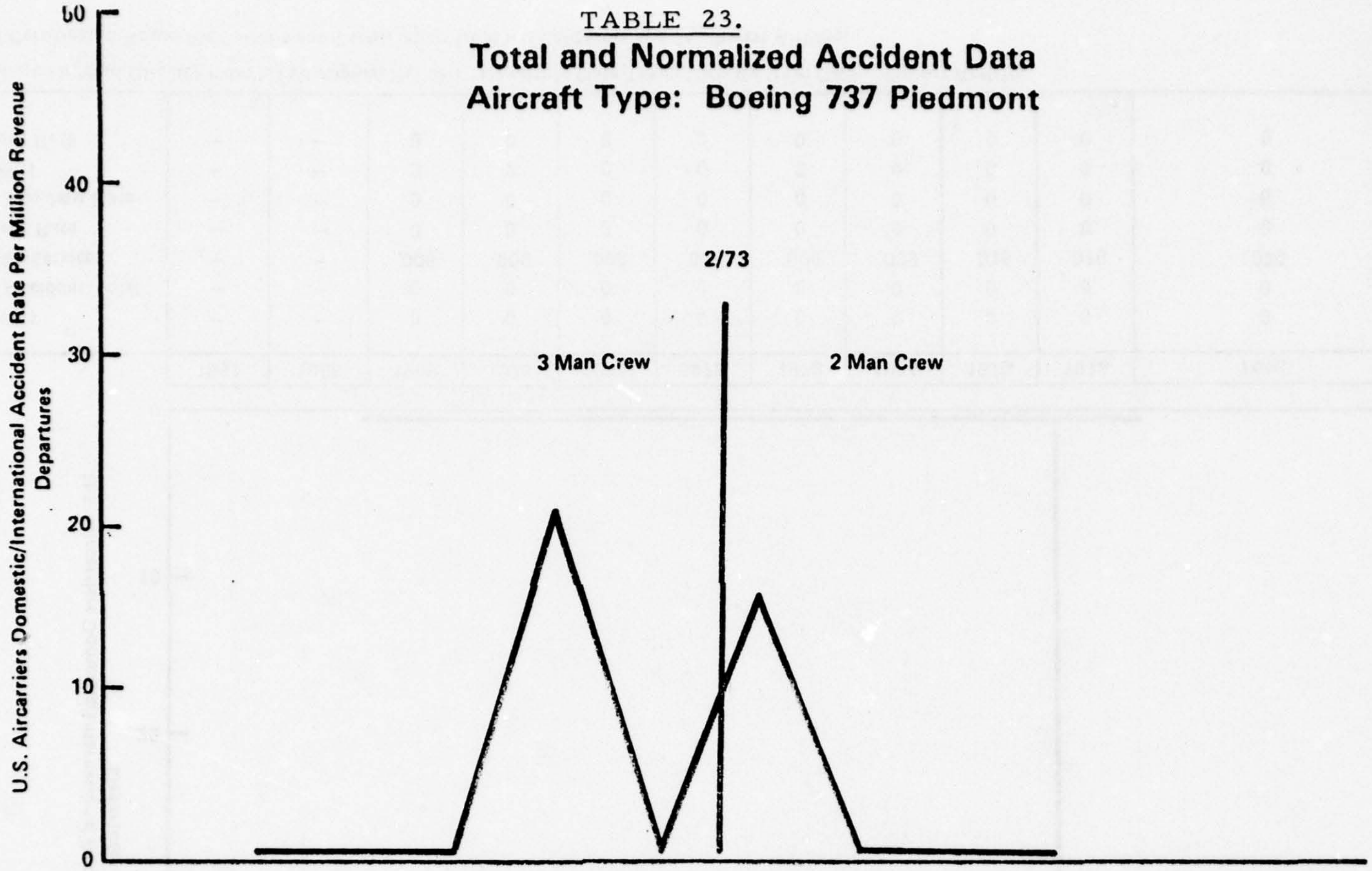


	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	–	–	0	0	0	0	3	0	0	0	3
Normalized Accident Total	–	–	0	0	0	0	2	0	0	0	2
Departures All Services	–	–	.005	.019	.030	.033	.041	.045	.049	.063	.285
Total Accident Rate	–	–	0	0	0	0	73.17	0	0	0	10.53
Normalized Accident Rate	–	–	0	0	0	0	48.78	0	0	0	7.02
Fatal Accidents	–	–	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	–	0	0	0	0	0	0	0	0	0

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB-- Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 23.

Total and Normalized Accident Data
Aircraft Type: Boeing 737 Piedmont

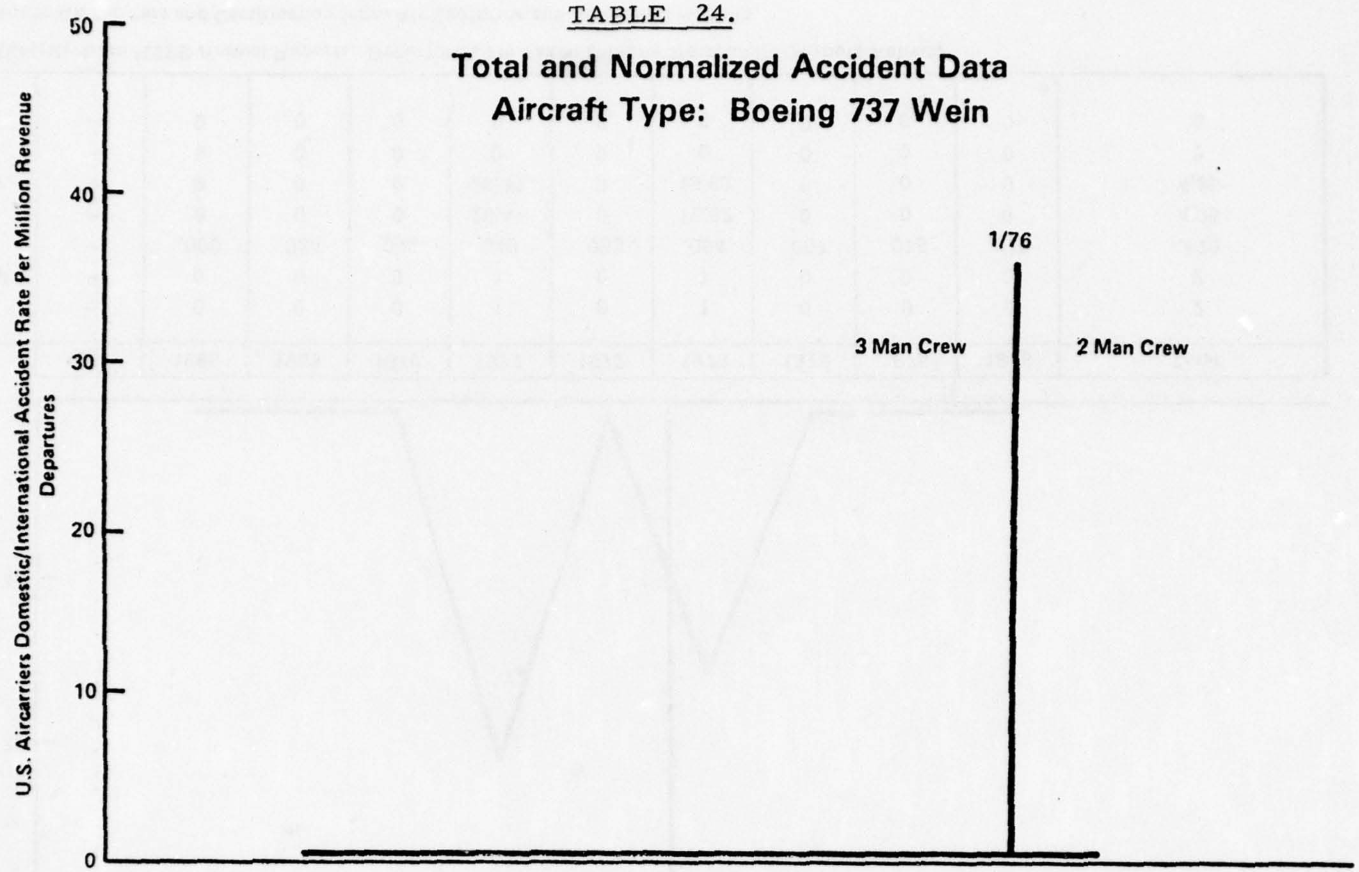


	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	–	0	0	0	1	0	1	0	0	0	2
Normalized Accident Total	–	0	0	0	1	0	1	0	0	0	2
Departures All Services	–	.009	.034	.042	.049	.053	.064	.067	.075	.077	.470
Total Accident Rate	–	0	0	0	20.41	0	15.62	0	0	0	4.25
Normalized Accident Rate	–	0	0	0	20.41	0	15.62	0	0	0	4.25
Fatal Accidents	–	0	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	0	0	0	0	0	0	0	0	0	0

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 24.

Total and Normalized Accident Data
Aircraft Type: Boeing 737 Wein



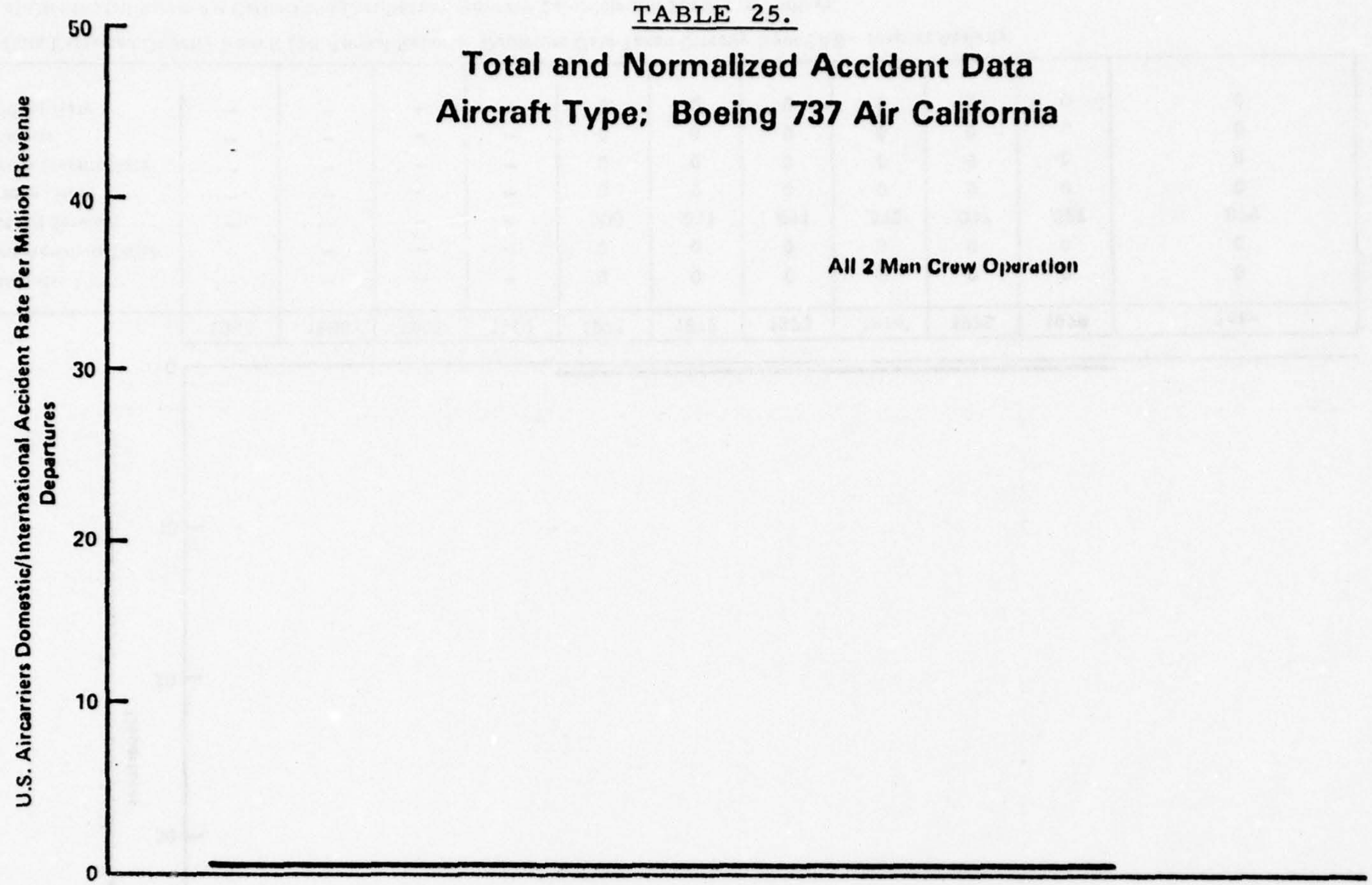
	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	–	–	0	0	0	0	0	0	0	0	0
Normalized Accident Total	–	–	0	0	0	0	0	0	0	0	0
Departures All Services	–	–	.005	.006	.008	.008	.009	.009	.015	.016	.076
Total Accident Rate	–	–	0	0	0	0	0	0	0	0	0
Normalized Accident Rate	–	–	0	0	0	0	0	0	0	0	0
Fatal Accidents	–	–	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	–	0	0	0	0	0	0	0	0	0

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 25.

Total and Normalized Accident Data

Aircraft Type; Boeing 737 Air California

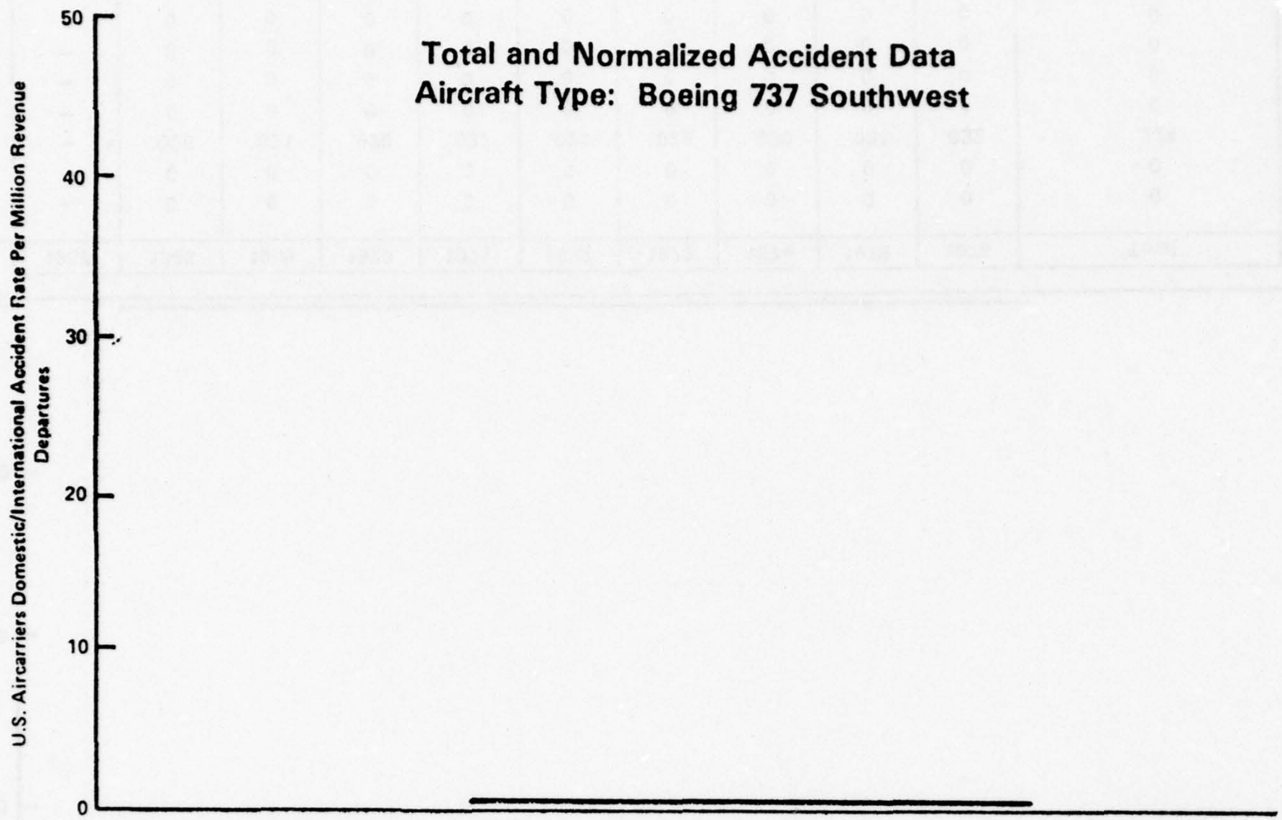


	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	–	0	0	0	0	0	0	0	0	0	0
Normalized Accident Total	–	0	0	0	0	0	0	0	0	0	0
Departures All Services	–	.006	.021	.020	.027	.027	.029	.030	.031	.032	.224
Total Accident Rate	–	0	0	0	0	0	0	0	0	0	0
Normalized Accident Rate	–	0	0	0	0	0	0	0	0	0	0
Fatal Accidents	–	0	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	0	0	0	0	0	0	0	0	0	0

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB– Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 26.

Total and Normalized Accident Data
Aircraft Type: Boeing 737 Southwest



	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Total Accidents	–	–	–	–	0	0	0	0	0	0	0
Normalized Accident Total	–	–	–	–	0	0	0	0	0	0	0
Departures All Services	–	–	–	–	.006	.011	.011	.012	.017	.022	.079
Total Accident Rate	–	–	–	–	0	0	0	0	0	0	0
Normalized Accident Rate	–	–	–	–	0	0	0	0	0	0	0
Fatal Accidents	–	–	–	–	0	0	0	0	0	0	0
Fatal Accident Rate	–	–	–	–	0	0	0	0	0	0	0

Accident Data Extracted Directly from NTSB Annual Reports. Departure Data Taken Directly from CAB-- Airport Activity Statistics of Certificated Route Air Carriers and Certification from Air California and Southwest Airlines.

TABLE 27.

Total and Normalized Data:

By Aircraft, Air Carrier and Crew Size

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
BAC 1-11											
Total Accidents	1	1	0	1	0	0	1	3	0	0	7
Normalized Accident Total	1	1	0	0	0	0	0	0	0	0	2
Departures – All Services	.185	.196	.203	.166	.130	.129	.128	.121	.114	.111	1.483
Total Accident Rate	5.40	5.10	0	6.02	0	0	7.81	24.79	0	0	4.72
Normalized Accident Rate	5.40	5.10	0	0	0	0	0	0	0	0	1.35
Fatal Accidents	1	0	0	0	0	0	0	0	0	0	1
Fatal Accident Rate	5.40	0	0	0	0	0	0	0	0	0	.67
Boeing 737											
Total Accidents	–	1	0	1	1	1	5	0	1	0	10
Normalized Accident Total	–	1	0	1	1	1	3	0	1	0	8
Departures – All Services	–	.079	.325	.374	.373	.393	.420	.410	.405	.433	3.212
Total Accident Rate	–	12.66	0	2.67	2.68	2.54	11.88	0	2.47	0	3.11
Normalized Accident Rate	–	12.66	0	2.67	2.68	2.54	7.13	0	2.47	0	2.49
Fatal Accidents	–	0	0	0	0	1	0	0	0	0	1
Fatal Accident Rate	–	0	0	0	0	2.54	0	0	0	0	.31
Two Man Crew-Departures	–	.006	.021	.020	.033	.038	.069	.139	.153	.165	.644
Total Accidents	–	0	0	0	0	0	1	0	0	0	1
Normalized Total Acc.	–	0	0	0	0	0	1	0	0	0	1
Fatal Accidents	–	0	0	0	0	0	0	0	0	0	0
Total Accident Rate	–	0	0	0	0	0	14.49	0	0	0	1.55
Norm. Tot. Acc. Rate	–	0	0	0	0	0	14.49	0	0	0	1.55
Fatal Acc. Rate	–	0	0	0	0	0	0	0	0	0	0
Three Man Crew-Departures	–	.073	.304	.354	.340	.355	.351	.271	.252	.268	2.568
Total Accidents	–	1	0	1	1	1	4	0	1	0	9
Normalized Total Acc.	–	1	0	1	1	1	2	0	1	0	7
Fatal Accidents	–	0	0	0	0	1	0	0	0	0	1
Total Accident Rate	–	13.70	0	2.82	2.94	2.82	11.36	0	3.96	0	3.50
Norm. Tot. Acc. Rate	–	13.70	0	2.82	2.94	2.82	5.68	0	3.96	0	2.72
Fatal Acc. Rate	–	0	0	0	0	2.82	0	0	0	0	.039

Total and Normalized Data:

By Aircraft, Air Carrier and Crew Size (CON'T)

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Douglas DC-9											
Total Accidents	1	2	6	3	7	7	6	5	0	4	41
Normalized Accident Total	1	2	5	3	5	6	4	2	0	4	32
Departures – All Services	.319	.710	1.018	1.099	1.139	1.166	1.161	1.114	1.107	1.174	10.007
Total Accident Rate	3.13	2.92	5.89	2.73	6.15	6.00	5.17	4.49	0	3.41	4.10
Normalized Accident Rate	3.13	2.92	4.91	2.73	4.39	5.15	3.44	1.79	0	3.41	3.20
Fatal Accidents	1	1	1	1	3	2	1	1	0	0	11
Fatal Accident Rate	3.13	1.41	0.98	0.91	2.63	1.71	0.86	0.90	0	0	1.10
Two Man Crew Operations BAC 1-11/DC-9/B-737											
Total Accidents	2	3	6	4	7	7	8	8	0	4	49
Normalized Accident Total	2	3	5	3	5	6	5	2	0	4	35
Departures – All Services	.504	.912	1.242	1.285	1.302	1.333	1.358	1.374	1.375	1.720	12.405
Total Accident Rate	3.97	3.29	4.83	3.11	5.38	5.25	5.89	5.82	0	2.32	3.95
Normalized Accident Rate	3.97	3.29	4.03	2.33	3.84	4.50	3.68	1.46	0	2.32	2.82
Fatal Accidents	2	1	1	1	3	2	1	1	0	0	12
Fatal Accident Rate	3.97	1.10	0.81	0.79	2.30	1.50	0.74	0.73	0	0	0.97
Three Man Crew Operations B-737											
Total Accidents	–	1	0	1	1	1	4	0	1	0	9
Normalized Accident Total	–	1	0	1	1	1	2	0	1	0	7
Departures – All Services	–	.073	.304	.354	.340	.355	.352	.271	.252	.268	2.568
Total Accident Rate	–	13.70	0	2.82	2.94	2.82	11.36	0	3.97	0	3.50
Normalized Accident Rate	–	13.70	0	2.82	2.94	2.82	5.68	0	3.97	0	2.72
Fatal Accidents	–	0	0	0	0	1	0	0	0	0	1
Fatal Accident Rates	–	0	0	0	0	2.82	0	0	0	0	.039

Total and Normalized Data:

By Aircraft, Air Carrier and Crew Size (CON'T)

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Boeing 727											
Total Accidents	6	12	11	7	10	8	5	9	7	11	86
Normalized Accident Total	3	8	9	5	5	5	4	5	6	4	54
Departures – All Services	.820	1.105	1.286	1.287	1.308	1.378	1.495	1.480	1.550	1.677	13.386
Total Accident Rate	7.32	10.86	8.55	5.44	7.64	5.80	3.34	6.08	4.52	6.56	6.42
Normalized Accident Rate	3.66	7.24	7.00	3.88	3.82	3.63	2.66	3.38	3.87	2.38	4.03
Fatal Accidents	1	0	2	1	1	0	0	2	1	2	10
Fatal Accidents Rate	1.23	0	1.55	0.78	0.76	0	0	1.35	0.64	1.19	0.75
Douglas DC-8											
Total Accidents	8	7	13	8	6	4	3	3	5	1	58
Normalized Accident Total	2	2	6	2	3	2	0	0	2	0	19
Departures – All Services	.217	.240	.277	.282	.294	.299	.280	.210	.194	.180	2.473
Total Accident Rate	36.87	29.16	46.93	28.36	20.41	13.38	10.71	14.28	25.77	5.55	23.45
Normalized Accident Rate	9.22	8.33	21.66	7.09	10.20	6.69	0	0	10.31	0	7.68
Fatal Accidents	1	0	0	1	0	1	1	0	0	0	4
Fatal Accident Rate	4.61	0	0	3.55	0	3.34	3.57	0	0	0	1.62

Total and Normalized Data:

By Aircraft, Air Carrier and Crew Size (CON'T)

Boeing 737 By Aircarrier	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
United[1]											
Total Accidents	–	1	0	1	0	1	0	0	0	0	3
Normalized Accident Total	–	1	0	1	0	1	0	0	0	0	3
Departures – All Services	–	.045	.165	.185	.144	.145	.146	.138	.117	.117	1.202
Total Accident Rate	–	22.73	0	5.43	0	6.94	0	0	0	0	2.49
Normalized Accident Rate	–	22.73	0	5.43	0	6.94	0	0	0	0	2.49
Fatal Accidents	–	0	0	0	0	1	0	0	0	0	1
Fatal Accident Rate	–	0	0	0	0	6.94	0	0	0	0	0.83
Western[2]											
Total Accidents	–	0	0	0	0	0	1	0	1	0	2
Normalized Accident Total	–	0	0	0	0	0	0	0	1	0	1
Departures – All Services	–	.019	.076	.081	.088	.090	.091	.079	.071	.072	.667
Total Accident Rate	–	0	0	0	0	0	10.99	0	14.08	0	2.99
Normalized Accident Rate	–	0	0	0	0	0	0	0	14.08	0	1.49
Fatal Accidents	–	0	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	0	0	0	0	0	0	0	0	0	0
Aloha[3]											
Total Accidents	–	–	0	0	0	0	0	0	0	0	0
Normalized Accident Total	–	–	0	0	0	0	0	0	0	0	0
Departures – All Services	–	–	.019	.021	.021	.026	.029	.030	.030	.033	.209
Total Accident Rate	–	–	0	0	0	0	0	0	0	0	0
Normalized Accident Rate	–	–	0	0	0	0	0	0	0	0	0
Fatal Accidents	–	–	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	–	0	0	0	0	0	0	0	0	0

[1] All 3 Man Crew Operations

[2] All 3 Man Crew Operations

[3] 3 Man Crew Thru 11/72 2 Man Crew Thereafter. All Departures for 1969 Thru December 31, 1972 Allocated to 3 Man Crew Operations

Total and Normalized Data:

By Aircraft, Air Carrier and Crew Size (CON'T)

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Boeing 737 By Aircarrier											
Frontier[4]											
Total Accidents	–	–	0	0	0	0	3	0	0	0	3
Normalized Accident Total	–	–	0	0	0	0	2	0	0	0	2
Departures – All Services	–	–	.005	.019	.030	.033	.041	.045	.049	.063	.285
Total Accident Rate	–	–	0	0	0	0	73.17	0	0	0	10.53
Normalized Accident Rate	–	–	0	0	0	0	48.78	0	0	0	7.02
Fatal Accidents	–	–	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	–	0	0	0	0	0	0	0	0	0
Piedmont[5]											
Total Accidents	–	0	0	0	1	0	1	0	0	0	2
Normalized Accident Total	–	0	0	0	1	0	1	0	0	0	2
Departures – All Services	–	.009	.034	.042	.049	.053	.064	.067	.075	.077	.470
Total Accident Rate	–	0	0	0	20.41	0	15.62	0	0	0	4.25
Normalized Accident Rate	–	0	0	0	20.41	0	15.62	0	0	0	4.25
Fatal Accidents	–	0	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	0	0	0	0	0	0	0	0	0	0
Wein[6]											
Total Accidents	–	–	0	0	0	0	0	0	0	0	0
Normalized Accident Total	–	–	0	0	0	0	0	0	0	0	0
Departures – All Services	–	–	.005	.006	.008	.008	.009	.009	.015	.016	.076
Total Accident Rate	–	–	0	0	0	0	0	0	0	0	0
Normalized Accident Rate	–	–	0	0	0	0	0	0	0	0	0
Fatal Accidents	–	–	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	–	0	0	0	0	0	0	0	0	0

[4] 3 Man Crew Thru 9/76 2 Man Crew Thereafter. All Departures for 1969 Thru Dec. 31, 1976 Allocated to 3 Man Crew Operations.

[5] 3 Man Crew Thru 2/73 2 Man Crew Thereafter. All Departures for 1969 Thru Dec. 31, 1973 Allocated to 3 Man Crew Operations. However, the One 1973 Accident is Properly Charged to 2 Man Crew Operations.

[6] 3 Man Crew Thru 1/76 2 Man Crew Thereafter. All Departures for 1969 Thru Dec. 31, 1976 Allocated to 3 Man Crew Operations.

Total and Normalized Data:

By Aircraft, Air Carrier and Crew Size (CON'T)

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Boeing 737 By Aircarrior											
Air California[7]											
Total Accidents	–	0	0	0	0	0	0	0	0	0	0
Normalized Accident Total	–	0	0	0	0	0	0	0	0	0	0
Departures – All Services	–	.006	.021	.020	.027	.027	.029	.030	.031	.033	.224
Total Accident Rate	–	0	0	0	0	0	0	0	0	0	0
Normalized Accident Rate	–	0	0	0	0	0	0	0	0	0	0
Fatal Accidents	–	0	0	0	0	0	0	0	0	0	0
Fatal Accident Rate	–	0	0	0	0	0	0	0	0	0	0
Southwest[8]											
Total Accidents	–	–	–	–	0	0	0	0	0	0	0
Normalized Accident Total	–	–	–	–	0	0	0	0	0	0	0
Departures – All Services	–	–	–	–	.006	.011	.011	.012	.017	.022	.079
Total Accident Rate	–	–	–	–	0	0	0	0	0	0	0
Normalized Accident Rate	–	–	–	–	0	0	0	0	0	0	0
Fatal Accidents	–	–	–	–	0	0	0	0	0	0	0
Fatal Accident Rate	–	–	–	–	0	0	0	0	0	0	0

[7] All 2 Man Crew Operations

[8] All 2 Man Crew Operations

Total and Normalized Data:

By Aircraft, Air Carrier and Crew Size (CON'T)

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Total
Boeing 737 Departures											
By Aircarrier											
Total											
United	–	.045	.165	.185	.144	.145	.146	.138	.117	.117	1.202
Western	–	.019	.076	.081	.088	.090	.091	.079	.071	.072	.667
Aloha	–	–	.019	.021	.021	.026	.029	.030	.030	.033	.209
Frontier	–	–	.005	.019	.030	.033	.041	.045	.049	.063	.285
Piedmont	–	.009	.034	.042	.049	.053	.064	.067	.075	.077	.470
Wein	–	–	.005	.006	.008	.008	.009	.009	.015	.016	.076
Air California	–	.006	.021	.020	.027	.027	.029	.030	.031	.033	.224
Southwest	–	–	–	–	.006	.011	.011	.012	.017	.022	.079
Total	–	.079	.325	.374	.373	.393	.420	.410	.405	.433	3.212

Total and Normalized Data:

By Aircraft, Air Carrier and Crew Size (CON'T)

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	TOTAL
Boeing 737 Departures											
By Aircarrier											
Allocated By Crew Size											
3 Man											
United	–	.045	.165	.185	.144	.145	.146	.138	.117	.117	1.202
Western	–	.019	.076	.081	.088	.090	.091	.079	.071	.072	.667
Frontier	–	–	.005	.019	.030	.033	.041	.045	.049	.063	.285
Wein	–	–	.005	.006	.008	.008	.009	.009	.015	.016	.076
Piedmont	–	.009	.034	.042	.049	.053	.064				.251
Aloha	–	–	.019	.021	.021	.026					.087
Total		.073	.304	.354	.340	.355	.351	.271	.252	.268	2.568
2 Man											
Piedmont								.067	.075	.077	.219
Aloha							.029	.030	.030	.033	.122
Aircalifornia	–	.006	.021	.020	.027	.027	.029	.030	.031	.033	.224
Southwest	–	–	–	–	.006	.011	.011	.012	.017	.022	.079
Total		.006	.021	.020	.033	.038	.069	.139	.153	.165	.644

1977/1978 TASK FORCE ON CREW WORKLOAD

DOUGLAS DC-9 MIDAIR COLLISIONS

NTSB NUMBER	DATE
1-0002	3/9/67
1-0012	3/27/67
1-0052	2/6/69
1-0016	9/9/69
1-0005	6/6/71
1-0021	12/4/71

1-0002; 3/9/67; Douglas DC-9

Collision with aircraft - both in flight. DC-9 provided traffic information at 12:30 1 mile. This warning was acknowledged 14 seconds before the collision. The cockpit voice recorder indicates that the DC-9 crew never detected the traffic reported to them even though it was displayed in the clear glass areas of the windshields before the traffic advisory was issued. The DC-9 crew was in a better position to see-and-avoid the other aircraft. Approximately 5 seconds should have been sufficient to detect the target and initiate a change in direction of the DC-9. The aircraft response time would have been approximately 3 seconds. There is no evidence of any attempted action by either crew.1/ The flight recorder readout indicates that the DC-9 was operating at a speed of 323 knots at the time of the collision within approximately 25 nautical miles from the point of intended landing.2/

Size of flight deck crew - no factor.

1/ NTSB aircraft accident report Mar 9, 1967 N. Urbana, OH, p 40

2/ NTSB aircraft accident report Mar 9, 1967 N. Urbana, OH, p 33

1-0012; 3/27/68; Douglas DC-9

Collision with aircraft - both in flight. Two fully rated and current DC-9 captains and one First Officer were the flight deck crew. The tower issued a traffic advisory to the DC-9 regarding the other aircraft approximately 41 seconds before the accident. Ozark pilots, if exercising reasonable vigilance, could have sighted the CESSNA in time to avoid the collision. The CESSNA crew could not have been expected to see-and-avoid the DC-9[1/]. Based on a fixed eye reference point, only the First Officer had a protracted length of time during which the other aircraft would have been visible in the last minute before collision.[2/] The third crew member had two short 6 sec. intervals approximately 12 sec. apart where he could have but did not see the other aircraft.[3/]

Size of flight deck crew - no factor.

1/ NTSB aircraft accident report Mar 27, 1968 St. Louis, MO. p. 18.

2/ NTSB aircraft accident report Mar 27, 1968 St. Louis, MO. p. 15.

3/ NTSB aircraft accident report Mar 27, 1968 St. Louis, MO. p. 11.

1-0052; 2/6/69; Douglas DC-9

The accident occurred just before midnight. The weather was VFR. The small aircraft was operating in a closed left hand pattern. The Douglas DC-9 was making a long straight-in VFR approach. No tower was available. The initial IFR clearance, which was subsequently cancelled by the pilot, was issued from Brownsville, Texas. Unicom frequencies were not used by either aircraft to advise each other of their locations.

REILS were operating at the approach end of the active runway. The DC-9 crew were asked, by ground personnel to evaluate the lights - certainly a distraction.

The small aircraft was below the DC-9 horizon and buried in the lights of the town of Harlingen.

DC-9 crew first saw a shadow of an aircraft pass over them and felt a thud of the midair mid-air collision. They estimated that the collision occurred approximately 1 mile from the runway.

1-0052; 2/6/69; Douglas DC-9 (Cont'd)

The small aircraft was carried to the airport and dropped on the runway. The pilot, the sole occupant, was seriously injured.

It is questionable that the DC-9 crew could have seen the small aircraft. However, the pilot of the small aircraft should have seen the DC-9.

1-0016; 9/9/69; Douglas DC-9

Collision with aircraft - both in flight. Deficiencies in ATC collision avoidance system. The DC-9 was descending at approx. 2460 feet per minute and at an indicated airspeed of from 236 to 253 knots out of a cloud base 4000 to 2500' assigned. Accordingly, the DC-9 crew would be unable to initiate a scan for unknown traffic until 14 seconds before the collision point. Same applies to other pilot.[1] The NTSB concluded, that based on several cited studies that 15 seconds is the absolute minimum time for detection, evaluation, and evasive action if the collision is to be avoided. On this basis, neither the DC-9 crew nor the other pilot would have had sufficient time to see-and-avoid the other aircraft even if they had devoted

1/ NTSB aircraft accident report Sep 9, 1969 - N. Fairland, Ind., p 10.

1-0016; 9/9/69; Douglas DC-9 (Cont'd)

virtually their entire attention outside the cockpit, scanning for other aircraft.[1]

1-0005; 6/6/71; Douglas DC-9

Collision with aircraft - both in flight. Three independent radar systems failed to detect the primary target of the other aircraft - that military aircraft did not have an operating transponder and had not asked for radar advisory service.[2] No traffic advisory concerning the military aircraft was given the DC-9. At least 40 seconds prior to impact the military aircraft was less than 45° to the left of the DC-9 Captain's

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1/ NTSB aircraft accident report Sep 9, 1969 - N. Fairland, Ind., p. 11

2/ NTSB accident report 6/6/71, N. Durante, California, p. 2

1-0006; 6/6/71; Douglas DC-9 (Cont'd)

and First Officer's normal sight line.[1] In this case, the likelihood of a pilot either not seeing an intruder at all or seeing the intruder and misinterpreting visual clues and then attempting an evasive maneuver based upon incomplete visual cues is highly possible.[2] The two crews had only marginal capability to detect, assess and avoid collision.[3]

Size of flight deck crew - no factor.

1/ NTSB accident report 6/6/71, N. Durante, California, p. 19

2/ NTSB accident report 6/6/71, N. Durante, California, p. 24

3/ NTSB accident report 6/6/71, N. Durante, California, p. 27

1-0021; 12/4/71; Douglas DC-9

Collision with aircraft - both in flight. Traffic control personnel inadequacy of ATC facilities and services in terminal area. DC-9 descended on to CESSNA. The relative flight paths of the two aircraft and the configurations physically limited each flight crew's ability to see-and-avoid the other aircraft.1/ The investigation disclosed that the CESSNA was not visible to the flight crew of the DC-9 during the period of time that the DC-9 was in visual meteorological conditions below the clouds since the CESSNA was below the DC-9's normal visual horizon.2/ The DC-9 remained behind and in the blind spot of the other aircraft until just before impact.3/

Size of flight deck crew -- no factor.

1/NTSB aircraft accident report 12/4/71 Raleigh, N.C. p.1

2/NTSB aircraft accident report 12/4/71 Raleigh, N.C. p. 5

3/NTSB aircraft accident report 12/4/71 Raleigh, N.C. p. 5

APPENDIX IV

SUMMARY OF RECENT CREW WORKLOAD EVALUATION PROGRAMS

General

This section contains material that illustrates the scope of the programs and the specific methods utilized in evaluating crew workload. The aircraft programs referred to are the B-737 and the later B-747, as well as the DC-9. Only two of these aircraft, the earlier ones by each manufacturer, were proposed for certification with two-man crews. Hence, it was for these development efforts that crew workload was specially highlighted as an area for thorough documentation. The later aircraft programs benefited, however, from the rapidly evolving state of workload measurement technology. Thus, it will be seen that increasingly more sophisticated tools were available for crew studies.

Evolution of workload measurement methods and techniques has paralleled the evolution of successively more advanced aircraft systems. Objectives for such methods and techniques have been to assure, from the earliest possible development phase, that crew provisions (in the form of crew complement, control-display features, and procedures) could in fact satisfy the demands on the crew of both normal and contingency operations.

Use of workload methods and techniques by industry has progressed in both military and commercial projects and methods continue to evolve. New techniques are employed as they are agreed to be useful. Useful methods now being applied include:

- Laboratory mockup studies, with flight crew evaluating arrangement and procedures according to a preliminary operational scenario. Access, visibility, proximity of related operations, and operability are confirmed.

- Analyses verifying that visual, physical and information requirements are suitably presented. These frequently use task timeline as well as time and motion methods coupled with review and appraisal by experienced crewmen in order to assure that performance time is reasonable and performance requirements are feasible. These techniques are being refined and updated with the development of new tools and data.

- o Simulation of both "part task" and "whole task" elements, to assure that potentially complex individual tasks are well within normal abilities and that the total composite of tasks will be manageable.

- o Flight test, including "part task" flight test in existing airplanes to verify effectiveness of provisions for potentially complex tasks, through full-scale flight test of the cockpit of the new airplane to validate crew complement and workload.

Since the evolution and confirmation of the practical applications for each such technique is a continuing process, the methodology applied for a given development program is based on the best available state-of-the-art at the time that program is initiated.

Specific programs, Boeing

During development of the 707, related military transport aircraft, and even the 727, the primary methods of "workload" certification were relatively simple. Mockup reviews by experienced pilot and pilot engineers were used extensively and workload suitability was confirmed by inspection/evaluation in the functional and reliability phases of flight test. Increasing use of simulation may be noted, phased from part task evaluations of handling qualities through more sophisticated control system simulations.

During B-737 certification, a more substantiated and documented examination was concluded very early to be necessary, because of the need to substantiate safety of operation with the reduction in pilot crew from the more conventional complement. Accordingly, a very extensive program was undertaken to evaluate and design the layout arrangement and configurations of the various cockpit controls and displays, and of automated features used to reduce workload demands. (Figures IV-1, IV-2, IV-3)

The schedule of certification progress on the B-737 is shown in Table IV-1. It will be noted that this crew workload evaluation effort stretched out over the period from late 1964 to December 1967, a total of over three years. Earliest data collection efforts were in those areas that could be started with crew station mockups. Specific comparisons with the reference flight deck, that of the B-727, began eight months

later, with various comparisons against other aircraft being added. More complete simulations and more realistic test situations were developed as the details of the flight deck were worked out. Simultaneously, computer simulations were conducted. Hence, work went on at several levels of realism with the available tools.

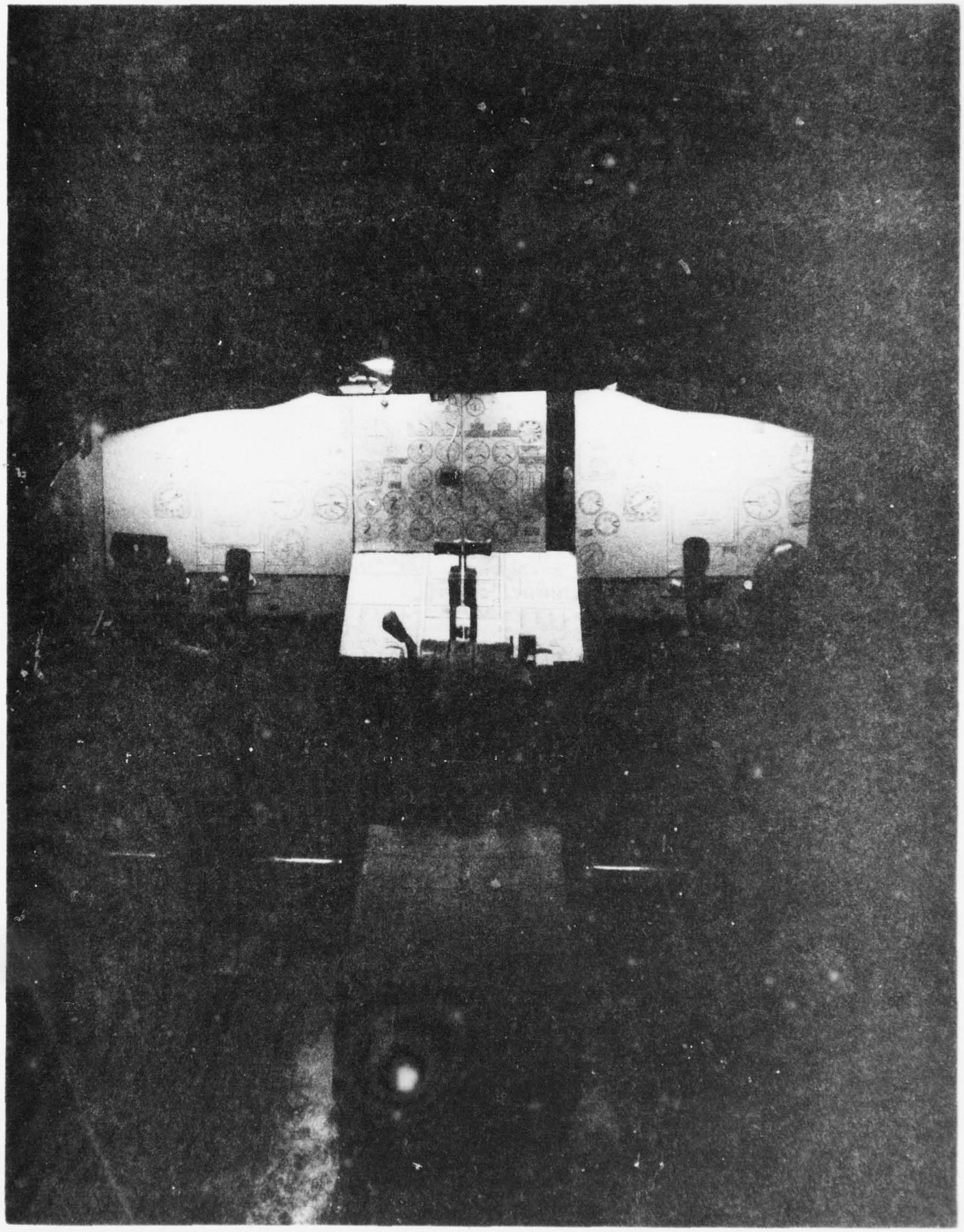

Figure IV-1 737 Lighted Cab Mockup

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SUMMARY REPORT OF 1977-1978 TASK FORCE ON CREW WORKLOAD.(U)
DEC 78 G C HAY, C D HOUSE, R L SULZER

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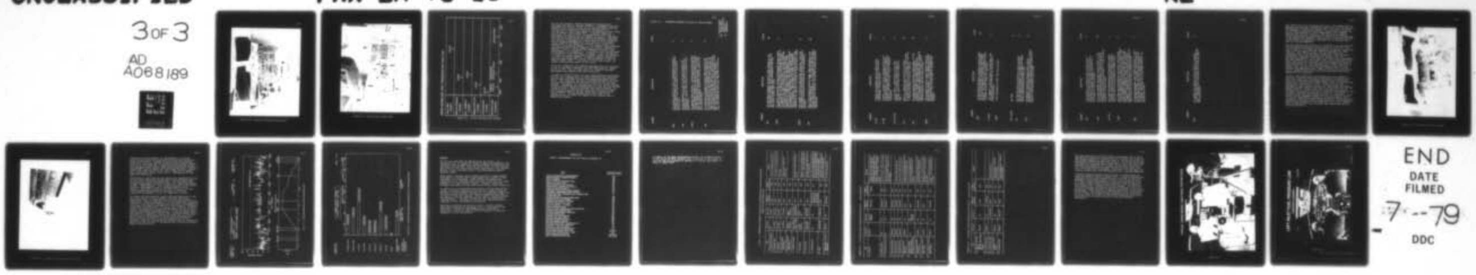

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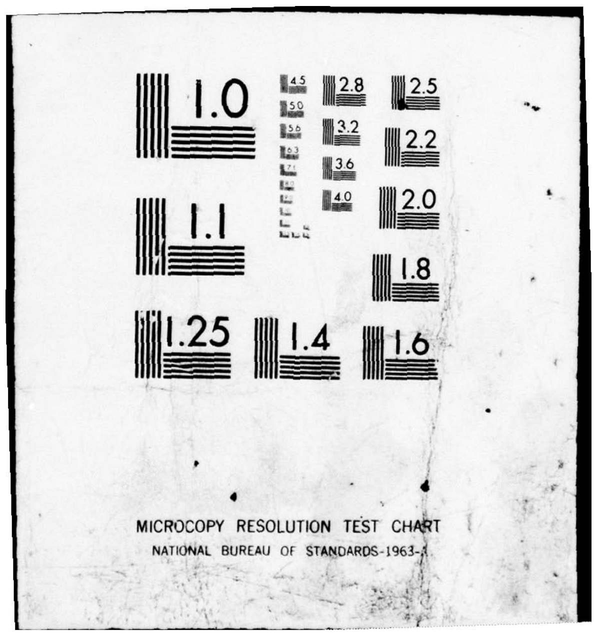
1.0
1.1
1.25
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6.3
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

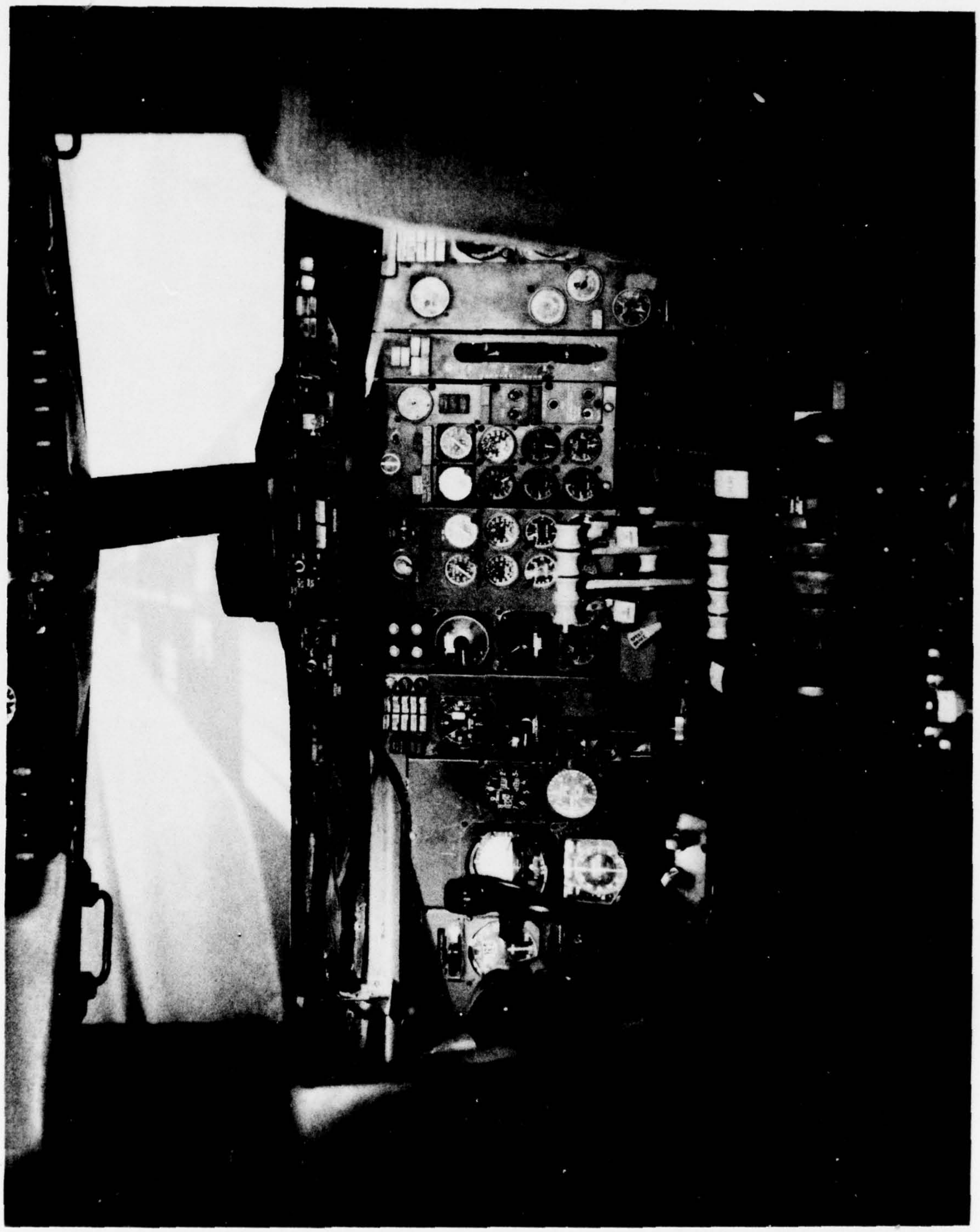

Figure IV-2 Design Configuration Simulator

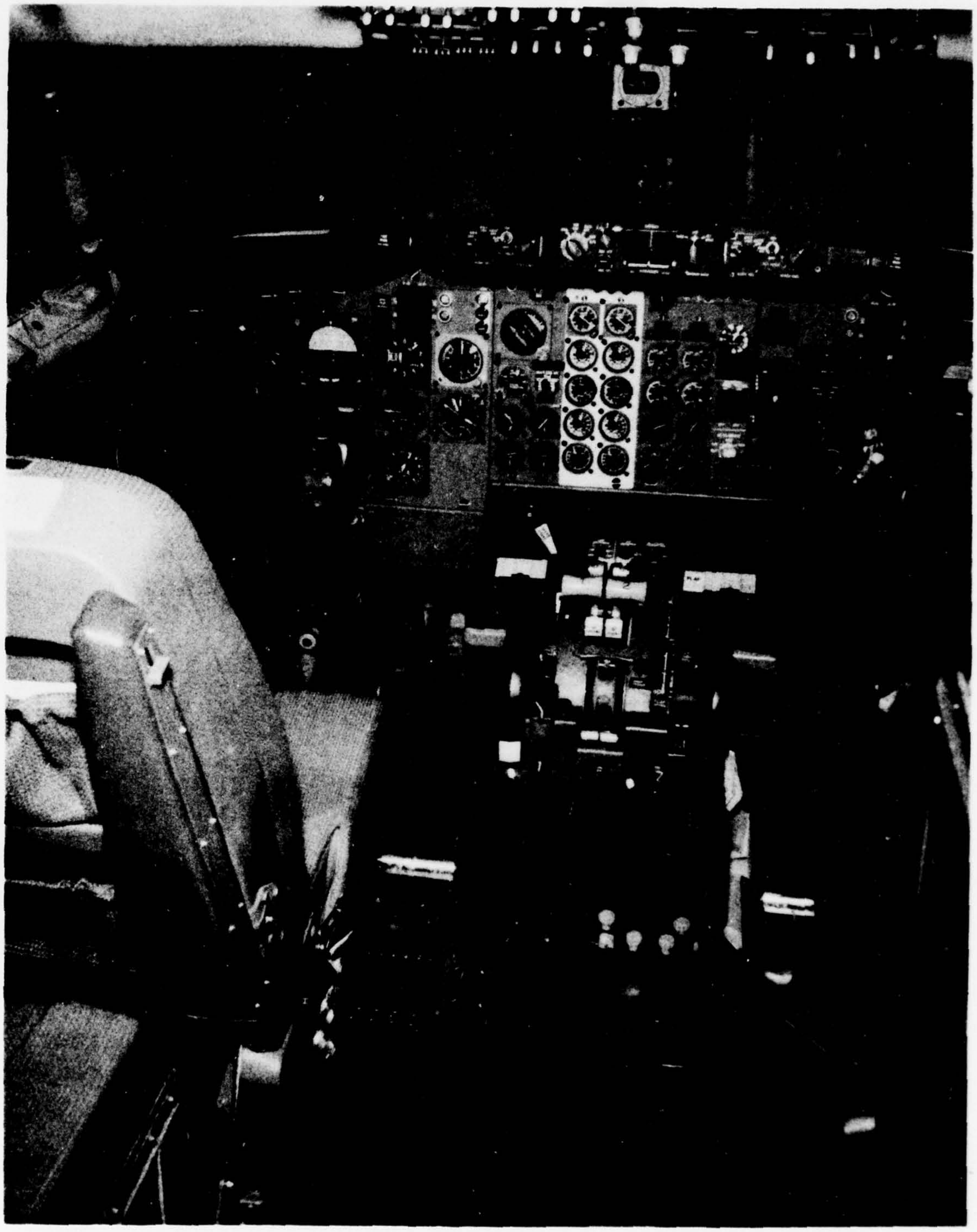

Figure IV-3 Operational Flight Deck

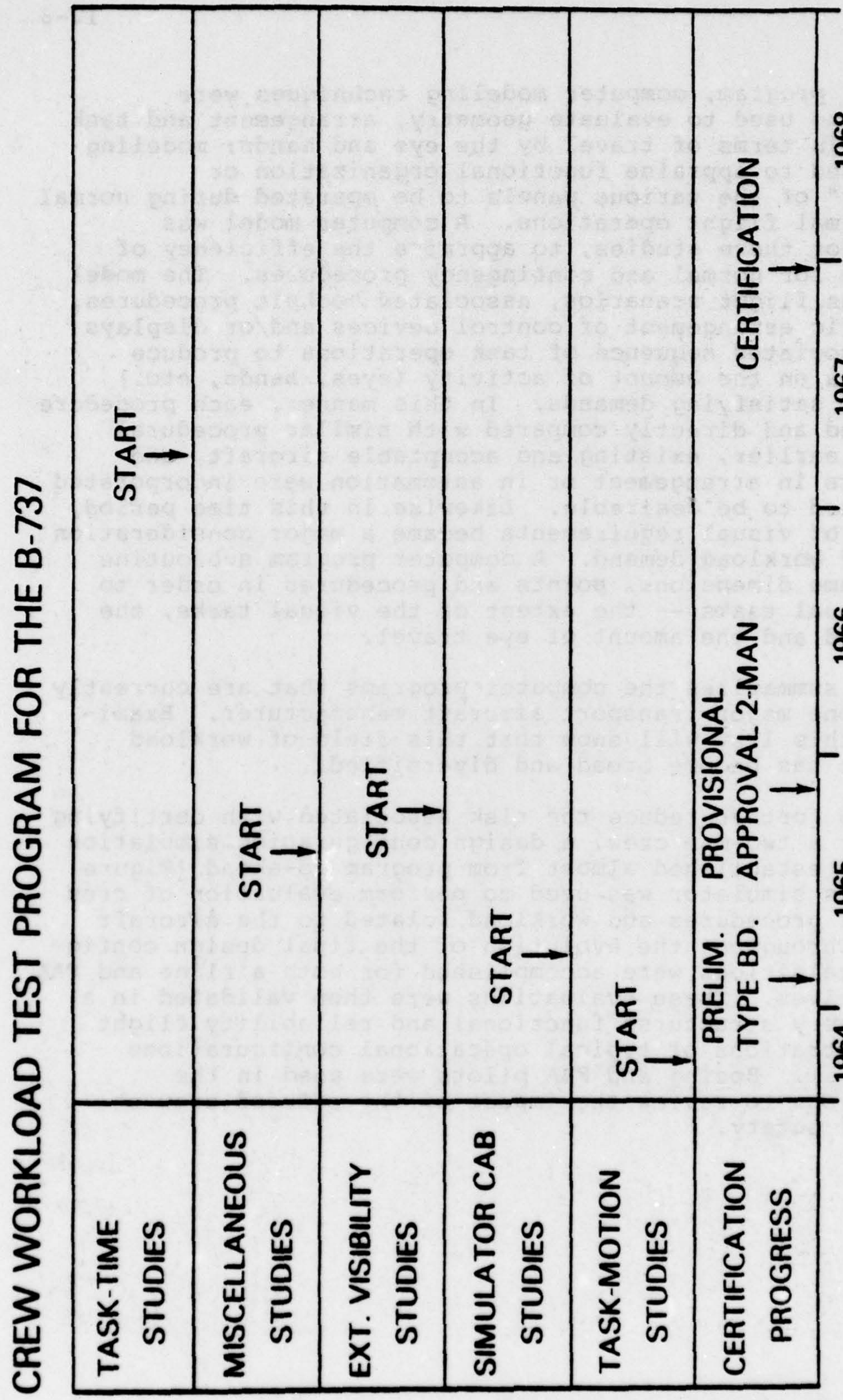

TABLE 28. B-737 Crew Workload Program

For the 737 program, computer modeling techniques were developed and used to evaluate geometry, arrangement and task sequencing in terms of travel by the eye and hands; modeling was also used to appraise functional organization or "efficiency" of the various panels to be operated during normal and off-normal flight operations. A computer model was developed for these studies, to appraise the efficiency of performance for normal and contingency procedures. The model used various flight scenarios, associated cockpit procedures, the geometric arrangement of control devices and/or displays and the associated sequence of task operations to produce summary data on the amount of activity (eyes, hands, etc.) involved in satisfying demands. In this manner, each procedure was examined and directly compared with similar procedural demands in earlier, existing and acceptable aircraft, and improvements in arrangement or in automation were incorporated as determined to be desirable. Likewise in this time period, the extent of visual requirements became a major consideration in terms of workload demand. A computer program subroutine used the same dimensions, points and procedures in order to examine visual tasks -- the extent of the visual tasks, the visual field and the amount of eye travel.

Table IV-2 summarizes the computer programs that are currently in use by one major transport aircraft manufacturer. Examination of this list will show that this field of workload measurement has become broad and diversified.

In order to further reduce the risk associated with certifying the 737 for a two-man crew, a design configuration simulation program was established almost from program go-ahead (Figure IV-2). This simulator was used to perform evaluation of crew operational procedures and workload related to the aircraft systems. Throughout the evolution of the final design configuration, evaluations were accomplished for both airline and FAA representatives. These evaluations were then validated in a series of very structured functional and reliability flight test demonstrations of typical operational configurations (Figure IV-3). Boeing and FAA pilots were used in the demonstrations to review the impact of the reduced crew on operational safety.

TABLE 29. COMPUTER PROGRAMS UTILIZED BY CREW SYSTEMS

PROGRAM	DESCRIPTION	STATUS
BMD	This program consists of a set of subprograms (Biomedical Computer Programs) which offer capabilities in description and tabulation, multivariate analysis of variance and special areas.	D
CAD	The CAD subprogram is a part of the CAFES program (see reference 12). It provides crew station allocation and configuration layouts, reach analysis, and escape analysis capabilities.	R
CAFES	The Computer Aided Function - Allocation Evaluation System (CAFES) Program consists of a set of subprograms which aid in human factors engineering functions for design, development, and operations of man-machine systems. It provides tools for man/equipment trade-offs, workload analysis and crew station design.	R
CAR	The Crewstation Assessment of Reach (CAR) Program serves as a tool for ascertaining percentage of pilots that (1) can be positioned at an eye reference point (ERP) (2) can reach specific hand and leg controls while positioned as close as possible to the ERP, (3) have a specified minimum head clearance while positioned as close as possible to the ERP. The program utilizes a link-man model within a specified crewstation utilizing a Monte Carlo simulation.	D

D - Design Support
DR - Design Application Research
RD - Research Development

PROGRAM	DESCRIPTION	STATUS
CGE	The Crewstation Geometry Evaluation (CGE) Program is used to study reach problems, visual interference problems, and specification compliance using anthropometric data and the cockpit design under study.	RD
CISMS	The Cockpit Information Storage and Management System (CISMS) Computer Program is used for computer storage and retrieval of all operator action/information tasks with related hardware characteristics, signal characteristics, and crew system data. The system is designed to allow data retrieval using any combination of Flight Phases, Flight Requirements, Flight Functions, Sub-system Elements, and Control/Display Functions, by assignment of a Dewey Decimal data access coding to each level of indenture. Approximately 40 fields of information related to each task may be stored and may be recalled in any combination to construct a multitude of required report formats.	D
CREVS	This program is used to study external visibility. Given the head rotation point, eye position, and aircraft transparencies, the program calculates eye deflections of the transparency outlines.	D
FAM	This is the Function Allocation Model (FAM) Subprogram of the CAFES Program (reference). FAM is used to identify and allocate tasks and functions to be assigned to each crew-member, identify required equipment, and evaluate selected man/machine combinations.	RD

PROGRAM	DESCRIPTION	STATUS
F8 ASM	F8 ASM is the assembler used to create machine language for the Fairchild F8 Microprocessor from assembly language coding.	D
F8 SIM	F8 SIM is a program used to simulate the Fairchild F8 Microprocessor. Using the machine language generated from the F8 ASM Program and a prescribed scenario, the F8 SIM provides a way of debugging F8 programs.	D
G-C10 (TET1)	This program is a modification of the TX105 Program. It is used to calculate hand and eye task execution times given a sequence of tasks.	D
HFTE	HFTE is a computer program used to configure multi-function switches. It provides a description of switch functions by level and checks for conflicts in function assignment to switch locations.	DR
HOS	The Human Operator Simulation Program (HOS) utilizes a detailed configuration, standard operating procedures, stimuli, performance and behavioral data to generate procedure execution times, operations action statistics, detailed line history, operator decision analysis, and life cycle criteria.	RD
INSTR	This program is used to study internal vision and perform reach analysis. Given crewman positioning and crew station data, the program calculates eye deflection, line of sight angle of incidence and distance.	D

PROGRAM	DESCRIPTION	STATUS
MMSS	The Man Machine Stochastic Simulation Program (MMSS) is used to evaluate crew performance effectiveness and allow for comparison of alternate crew station concepts. The program utilizes a stochastic process in selecting action values and sequencing.	RD
PAPTAPE	This program is used to create a punched paper tape with which to have a ROM made for the Fairchild F8 Microprocessor.	D
PROBY	Early development of SWAT (see that program).	
TET1 (GC10)	See GC10.	D
TLA	The Timeline Analysis Program is used to evaluate the crew station workload. The program utilizes typical scenarios describing crew tasks and creates reports showing workload problem areas.	D
TX94	The Maneuver Simulation Program (TX94) produces perspective plots for both interior and exterior objects, and can be used to produce motion picture animation sequences of out-the-window vision fields.	D

PROGRAM	DESCRIPTION	STATUS
SBO	This program is a large data base program used to store and retrieve cockpit tasks required to be performed by various crew members by subsystem and relate that to specific behavior objectives for development of training programs.	D
SWAT	The System Workload Assessment Program (SWAT) is used to provide workload assessment of hand and eye motion using transition and dwell times related to design of individual control and display panels. It also estimates probability of task success.	RD
TAS 033	The Flight Deck Window Design Effectiveness Program (TAS 033) is used to provide calculations and plots related to polar vision angles for windows, field of view, and collision course detection probabilities.	D
TX105	The Flight Deck Certification and Control Cabin Design Evaluation Program (TX105) is used to aid in determination of the instrument panel positioning and indicators. The program computes geometric data related to eye and hand motion through a procedural series of tasks related to a scenario. Subroutines also allow plotting of polar coordinate vision for monocular, binocular and ambinocular plots as well as collision course steradian access.	D
WAM	The Workload Assessment Model (WAM) Subprogram is a part of the CAFES Program. It provides a tool to study crew workload against specified crew station configurations for typical scenarios utilizing standard operating procedures. This model was a development based on the previous WECC model.	D

PROGRAM	DESCRIPTION	STATUS
WECC	The Cockpit Crew Workload Program (WECC) was designed to statistically analyze and plot cockpit crew workloading data. This model was a forerunner of TLA and was used in 747 certification.	D

Even before B-737 certification was final, the methods used to appraise workload were advanced by human factor specialists and improvements on models and methods were initiated. According to information received from Boeing, hundreds of thousands of dollars were expended for such improvements under Company programs and military contracts, the aim being to develop better techniques for predicting the extent of workload demands in man-machine developments. Both outside recognized work and the services of consultants well-known in the industry were used in such developments.

From such efforts and evaluations, techniques were selected for the next Boeing airplane to be certified -- the B-747. For this airplane, the visual and procedural efficiency evaluations used in the 737 were modified, improved and applied. Additionally, time demands as well as task deficiency were conducted to be a key workload consideration, and the model called WECC (Workload Evaluation for Cockpit Crew) was developed and applied. This model required that all procedures and task demands be "time-lined," and it also tabulated peformance times to produce "percent workload" summations based on task-time demand vs. time available for discrete intervals of lapsed time. Use of this model produced a time history for percent workload levels that helped identify high or simultaneous time demands based on required timing for task performance, suggesting potential task conflicts deserving closer evaluation for resolution.

Further, these procedural time demands were very formally examined in lighted configuration mockups and simulators on which the normal and contingency operations were precisely controlled to simulate their performance under structured time constraints (Figures IV-4, IV-5). These were not only evaluated by participating pilots but video taped and later analyzed by human factors specialistis from Boeing and the FAA Western Region. Concurrently, the controllability of the airplane was evaluated in a special simulator developed for use in control dynamics evaluations in which an "iron bird" simulation of airplance characteristics, and eventually actual control system equipment effects on control dynamics, were validated. Additional evaluations of landing operations were conducted in Boeing's Visual Flight Simulator. High speed taxi and turn-off simulations were conducted very early in design, using a special test rig to confirm that ground operability would be suitable.

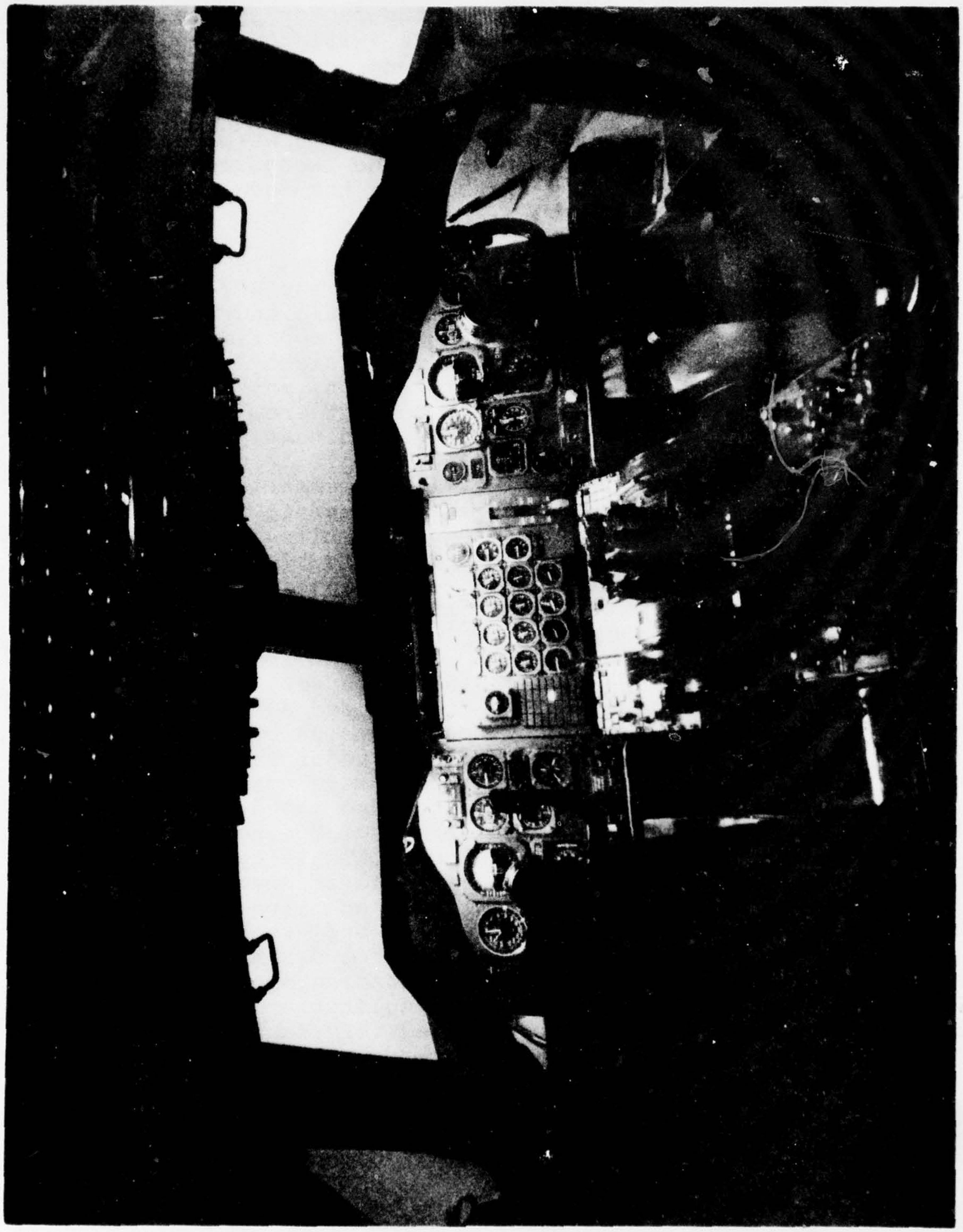

Figure IV-4. 747 Lighted Cab Pilot's Simulator

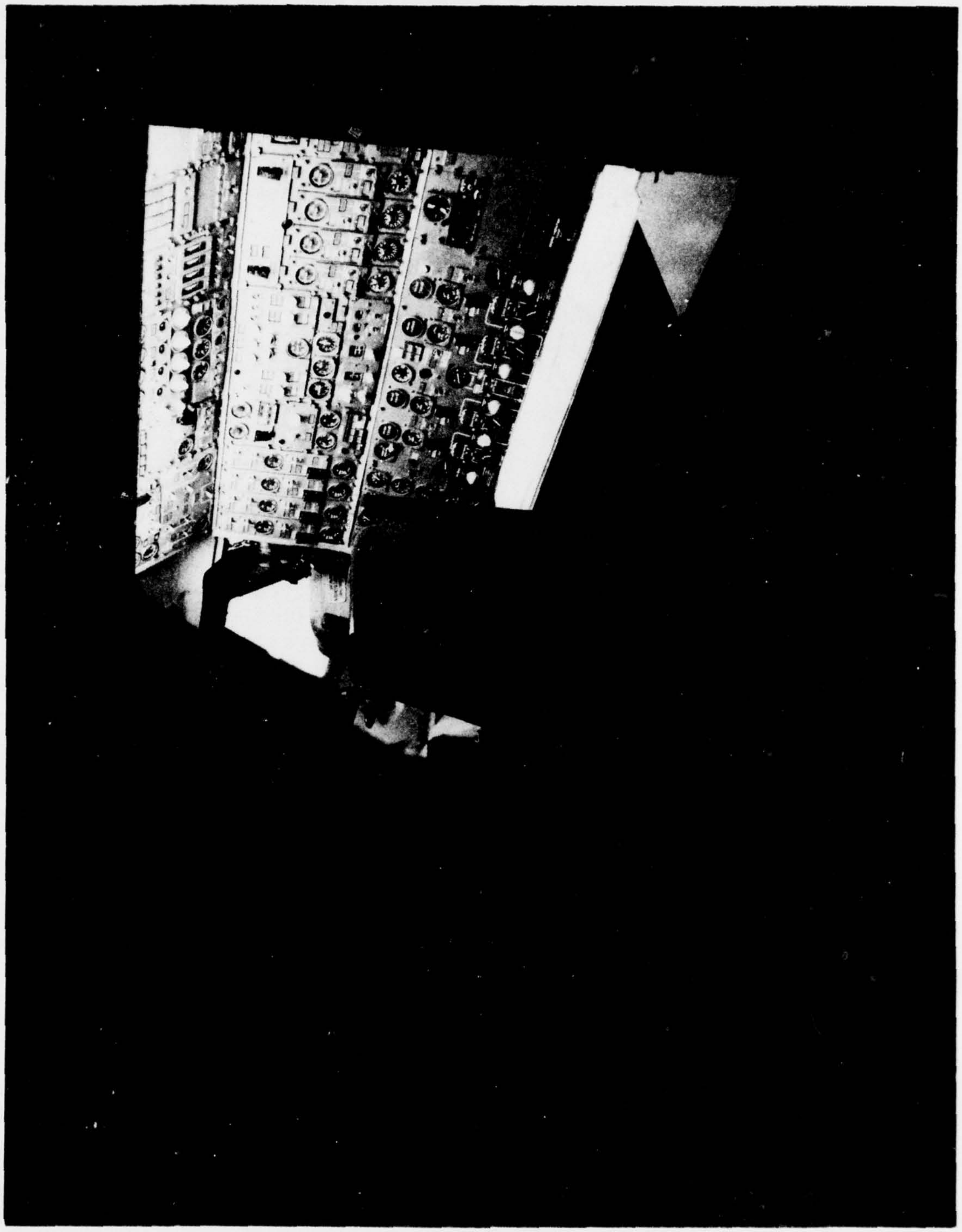

Figure IV-5. Lighted Cab Flight Engineer's Simulator

Examination and development of improvements in workload analysis and evaluation techniques have continued since the B-747 certification. Because of the concern for workload prediction techniques and the relation of new cockpit configurations on crew workload in future ATC and advanced flight deck equipment applications, NASA LRC contracted with Boeing to expand WECC analytic capability from the B-747 model, improve ease of use, and install it for use at NASA LRC to support their experiments (Figure IV-6, IV-7). Refinements of the model are continuing.

Additionally, within Boeing, new models were developed for use in evaluating individual system control and display configurations for workload considerations. One such model used during concept paper and pencil studies is a model designated as SWAT. Additionally, a new and more efficient pilot vision model was developed for use in windshield/pilot vision studies. This model considers not only the extent of crew vision demands but provides an estimate of collision probability assessment as well for comparison studies.

To assure the best possible layouts and configurations in the new flight decks of future product aircraft, additional improvements have included the area of workload evaluation in simulation. Studies conducted in a B-737 operational simulator (1972-1973 time period) developed and evaluated instrumentation techniques for assessing effects of crew workload in different flight deck configurations. Likewise, more recently a physiological instrumentation system was developed for use in future workload measurement experimentation. It was concluded that physiological techniques required more intensive operationally oriented investigation to explore for practical, utilitarian applications in development of flight deck configurations. Various efforts continue to further identify and refine analytic, modeling, and simulation methods that are relevant to appraising crew workload in developing and validating advanced cockpit configurations.

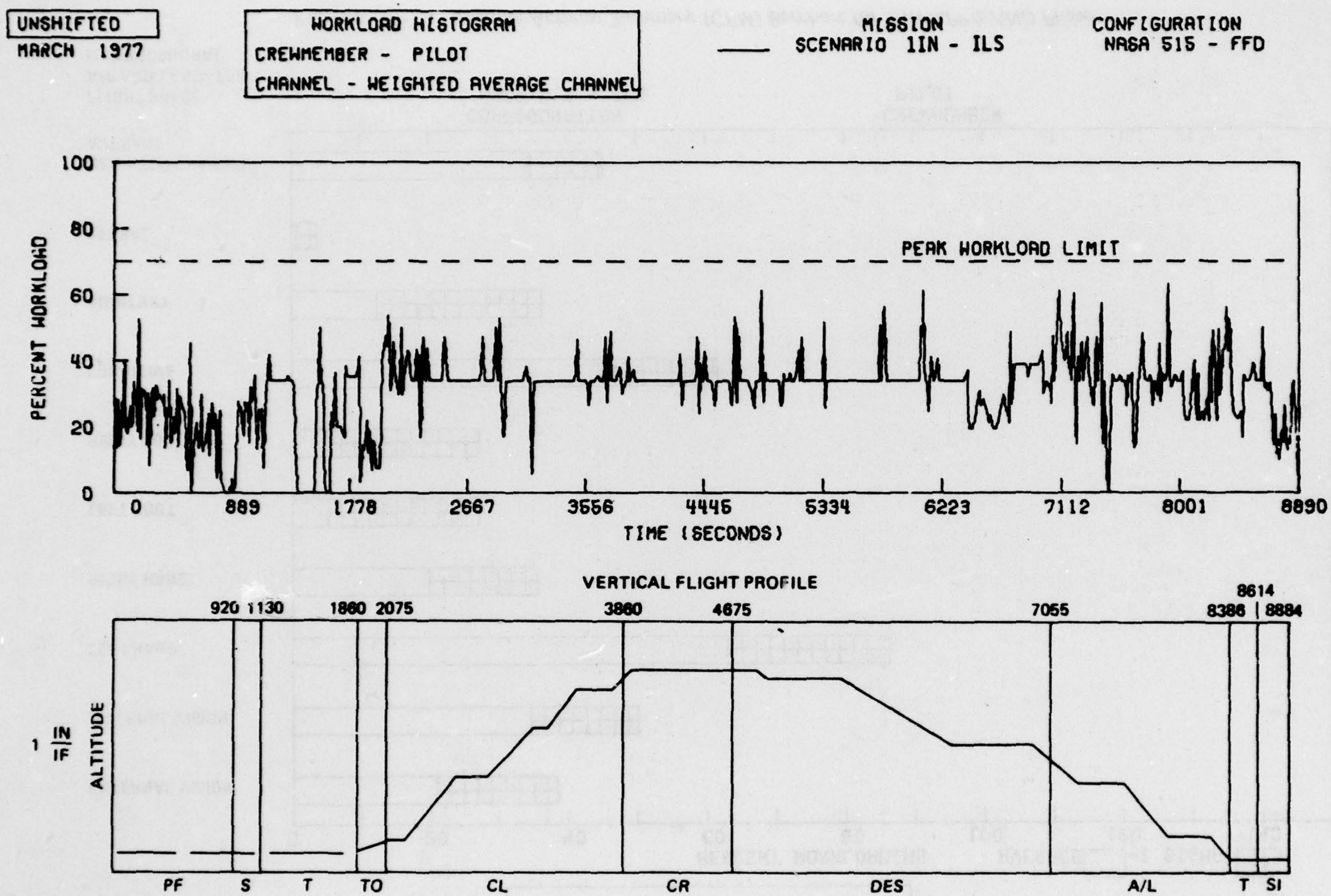

Figure IV-6. *Workload Histogram for Forward Flight Deck (FFD)*

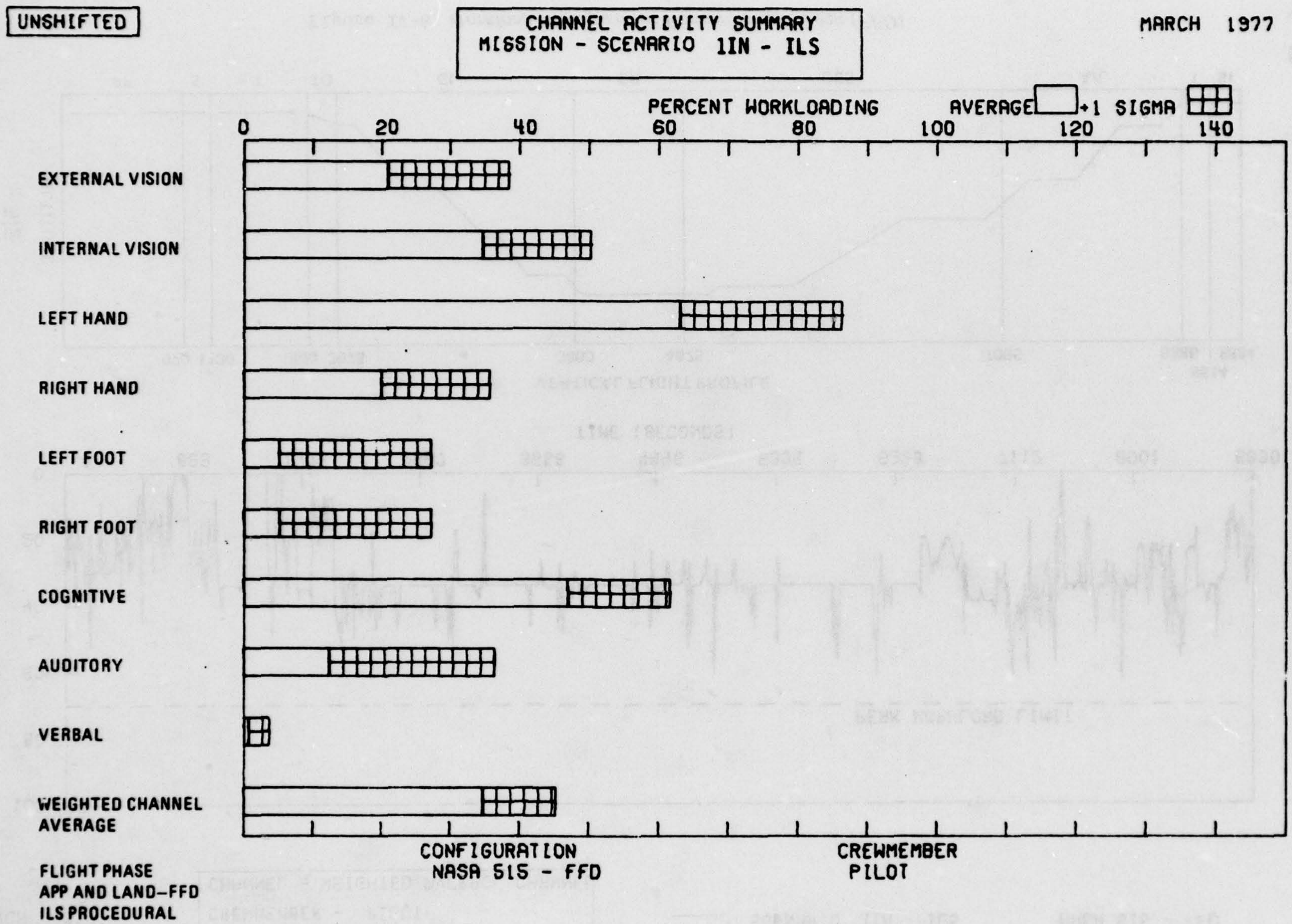

Figure IV-7. *Channel Activity Summary (CFM) Barchart for 1 IN APP/LAND Phase*

Douglas

The DC-9 was designed for operation by two pilots. To accomplish this a substantial design program was conducted with the stated goal of improving the DC-8 cockpit configuration and reducing crew workload. One well-known result of this development effort is the annunciator panel, duplicated in one form or another in many aircraft series, including smaller general aviation twins.

Three general methods were followed initially in DC-9 cockpit development. Display system improvements were tested in the laboratory and in mockups. Time-and-motion studies were conducted in the reference DC-8 in actual flight and in ground mockups of the new aircraft cockpit. Finally, crew task-analyses were made with the basis being actual flight scenarios.

In addition to the aforementioned central warning and caution system, workload reduction was claimed for a wide variety of systems, including simplifications in fuel displays, simplified air-conditioning controls, and flowline schematic representations of electrical systems. White cockpit lighting enabled the designers to use color coding and also to balance nite lighting better. Grouping of controls was improved based on frequency of use and relation of function.

With each successive series of aircraft, the DC-9 cockpit improvement program was extended, and as illustrated in the Table IV-3, individual improvements were installed on successive aircraft as soon as proven effective in workload reduction or pilot preference.

TABLE 30.

COCKPIT IMPROVEMENTS ON DC-9 PRIOR TO SERIES 50

ITEM	EFFECTIVITY (ACFT)
POSITIVE AUTOTHROTTLE DISENGAGEMENT	247
IMPROVED MANUAL PRESSURE CONTROL	386
BOW TIE DIMMING	397
SAFETY LATCH ON INSTRUMENT PANEL	535
CROSS TIE LOCKOUT LIGHT	557
PITCH ERECTION CUT-OFF COUPLING	557
IMPROVED STALL WARNING TEST SWITCH	573
LEVER LOCK BATTERY SWITCH	574
EMERGENCY POWER SWITCH MADE LUMINOUS	574
INSTRUMENT TRANSFORMER POWER MONITOR (COURSE INDICATOR – WARNING FLAG – HEADING LOSS)	582
FLAP/SPOILER LIGHT	589
REDUCED COCKPIT AIR CONDITIONING NOISE	600
IMPROVED PILOT'S FOOT WARMER	600
LANDING GEAR PROXIMITY SWITCHES	604
IMPROVED AUTOPILOT OFF LIGHT	612
STALL TEST SWITCH – 'T' HANDLE	616
COCKPIT SPEAKER MUTING	618
IMPROVED COCKPIT EMERGENCY LIGHT ACTUATION	621
ELIMINATE CABIN PRESSURE BUMP	625
ANTI-SKID PARKING BRAKE POWER MOD	632
EXTERNAL POWER DIODE	647
IMPROVED PILOT SEAT COMFORT	655
ANTI-SKID TEST IMPROVEMENT	686
IMPROVED AVIONICS RELIABILITY	686
ANTI-FOG WINDSHIELD SWITCH	687
PRESSURE SYSTEM POWER TRANSFER RELAY	701
SSRS HORN SOUND LEVEL REDUCTION	705
ALTIMETER – COUNTER POINTER	720
SSRS FAILURE WARNING IMPROVEMENT	733
RAT/EPR IMPROVED SELECTOR KNOB	RETROFIT
TAKEOFF WITH PARKING BRAKE – HORN	785
CIRCUIT BREAKER RELOCATION	SER 30 ON
BRAKE TEMPERATURE INDICATOR	SER 32 ON

A summary of the major differences between the standard series 30 and series 50 DC-9 aircraft with a notation of the effect on workload and the presence or absence of a safety improvement is shown in Table IV-4.

TABLE. 31. COMPARISON BETWEEN THE DOUGLAS STANDARD DC-9-30 AND DC-9-50 AIRPLANES

(EFFECT ON CREW WORKLOAD)

Item	DC-9-30	DC-9-50	Effect on Workload	Safety Improvement	Remarks
1. Wing Incidence Angle	0°	+1-1/4°	None	N/A	-50 wing incidence same as -40.
2. Fuselage length	119.3 feet	133.5 feet	None	N/A	-50 is about 14 feet longer than -30.
3. Wing span	93.4 feet	93.4 feet	None	N/A	No change.
4. Maximum Takeoff Gross Weight	114,000 lbs.	121,000 lbs.	None	N/A	-50 has structural beef-up in several areas
5. Engine and Takeoff Thrust Rating	JT8D-15 15,500 lbs.	JT8D-17 16,000 lbs.	None	N/A	
6. Airspeed Envelope	V_{MO}, 350 kts. V_{MO}, 84 Mach	V_{MO}, 340 kts. V_{MO}, 84 Mach	None	N/A	-50 has same airspeed envelope as the -40.
7. Fuel System	3 tanks Optional	4 tanks Yes	None	N/A	580 gallon forward auxiliary automati transfer. Same as some versions of -3
8. C.G. Limits	Fwd, +3.4% Aft, 36.0%	Fwd, -3.0% Aft, 34.7%	None	N/A	-50 Limits extended 6.4% more forwa and 1.3% further aft.
9. Fuselage strake	No	Yes	Eliminates flap rudder stop normal and abnormal procedures	Yes	Lower forward fuselage strake improve directional stability eliminating need for flap rudder stop and better engine-out minimum control speed.
10. APU	GTCP85-98D	FTCP85-DCK	None	N/A	-50 has 9% more air flow improved reliability and extended life.
11. APU automatic cooling (Shutdown)	Optional	Yes	Decreased	N/A	No monitoring required.

Comparison be. .en the Douglas Original Standard DC-9-30 and DC-9-. Airplanes (Continued)

Item	DC-9-30	DC-9-50	Effect on Workload	Safety Improvement	Remarks
12. Autopilot	SP-50A	Improved SP-50A	Decreased	Possible	Dynamic self test, radio altitude gain programming, turn entry softening making Heading Select operation more useable, thereby reducing the need for turn knob operation. IAS/MACH HOLD.
13. Engine Synchro	No	Yes	Decreased	N/A	Automatic Sync in climb, cruise descen
14. Canted Thrust Reversers	No	Yes	Decreased	Yes	Eliminates airspeed/power restrictions during landing roll. Improved icy run-way stopping.
15. Reverse Idle Detent	Optional	Yes	Decreased	N/A	
16. Altitude Alerting	Optional	Yes	Decreased	Yes	Altitude audio/visual alerting
17. Altitude Reporting	Optional	Yes	Decreased	Yes	Assists ATC in traffic flow control
18. Brake Temperature Indicators	Optional	Yes	None	Yes	Provides individual brake temperatures Assures Maximum brake energy
19. Ground Proximity Warning, including G/S Deviation Warning	No	Yes Complete Provisions	None	Yes	Audio warning of excessive sink or proximity and glideslope deviation warning.
20. Automatic Seat Belt/ No Smoking	Optional	Yes	Decreased	N/A	No Smoking off with gear retraction - Seat Belt off with slat retraction.
21. High Intensity Recog-nition Lights	Optional	Yes	None	Yes	Measurably improves day and night air craft recognition - also is a deterent bird strikes
22. Transponder on Ground Control Relay	Optional	Yes	Decreased	N/A	Prevents takeoff with transponder in standby - turns off after landing unle overridden

Comparison bet en the Douglas Original Standard DC-9-30 and DC-9-5. irplanes (Continued)

Item	DC-9-30	DC-9-50	Effect on Workload	Safety Improvement	Remarks
23. 50K HZ VAF/NAV Spacing 25K HZ VAF/COMM Spacing	Optional	Yes	None	N/A	
24. R-NAV Provisions	Optional	Yes	Decreased	N/A	
25. Annunciator Lights	-	6 Additional	None	N/A	Advisory lights only.
26. Standby Artificial Horizon	Optional	Yes	None	Yes	FAA requirement. Redundant Attitude Display.
27. Antiskid System	Optional	Mark IIIA	None	Yes	Improved performance. Better wet runway stopping.

The time duration of the DC-9 cockpit development and workload documentation program is illustrated by the fact that on May 20, 1963 Douglas Report No. 44232 was sent to the FAA and contained photographs of DC-9 two-man crew mockups. From this point, when a general configuration was already set up, work continued with many exhibits submitted to the type certification board until the final determination was made two and one-half years later that the flight deck arrangement, individual crew workload, and control accessibility were satisfactory for a two-man operation.

A typical workload analysis method using a ground mockup and video recording is shown in Figure IV-8. A special photographic technique, called the chronocyclegraph, was used to trace the movements of the pilots hands, as illustrated in Figure IV-9. In flight studies determined the total environmental workload for actual flight conditions by providing a full recording of DC-8 flights over a typical DC-9 route segment. An IFR flight from San Francisco to Stockton and return produced a full list of en-route communications, navigation activities, and checklist performance. The result was a demonstration that at any point in the flight, the cockpit design proposed for the DC-9 would allow one pilot to attend to corrective procedures alone while the other pilot flew the aircraft in the environmental conditions.

TYPICAL CREW WORK LOAD ANALYSIS METHOD

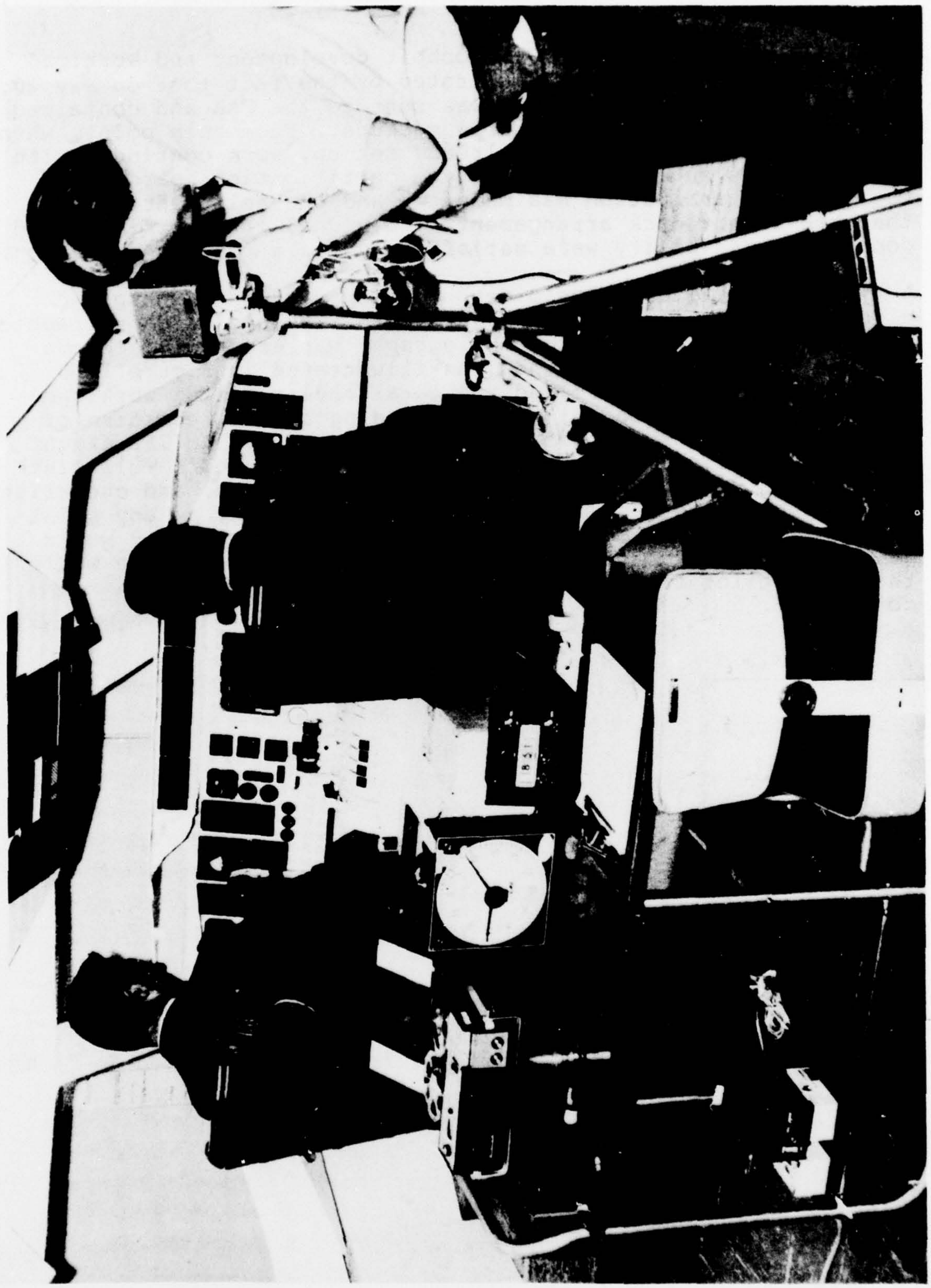

Figure IV-8

Figure IV-9

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